Weatherwise

VOLUME 13, NUMBER 6 DECEMBER 1960

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE"—BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

DAVID M. LUDLUM, *Editor* HENRY W. BULKLEY, *Associate Editor*

Colorado Site Selected for Headquarters of National Center for Atmospheric Research

SELECTION of Table Mountain near Boulder, Colorado, as site of headquarters for the National Center for Atmospheric Research has been announced by the National Science Foundation and the University Corporation for Atmospheric Research (UCAR).

Table Mountain was selected as the best available location for headquarters of the Center, in view of its central location with respect to research establishments and departments throughout the country, its excellent and growing research environment, and its advantages for the study of particular atmospheric phenomena. Because no single location could give access to all phenomena likely to be studied, however, the headquarters site may later be supplemented by field stations or supplementary research facilities elsewhere in the United States.

In making the announcement, Dr. Alan T. Waterman, Director of the National Science Foundation, said, "The Foundation has kept in close touch with the proceedings of the site survey—carried on by a UCAR committee—through the Director of the Center, Dr. Walter Orr Roberts. We believe UCAR has done a commendable job in carrying through on one of its most difficult and complex responsibilities, that of a site recommendation.

"We believe that this location will aid in the recruitment of top quality, well-trained scientists," he added. "The abilities of the central scientific group will directly affect the ultimate success of the National Center for Atmospheric Research."

Dr. Roberts stated: "The National Center will be primarily an intellectual enterprise, devoted to fundamental research on broad atmospheric problems. It will serve as a coordinating center for a wide ranging network of such investigations. This effort can be expected to develop a much more comprehensive understanding of weather and other phenomena than has ever been possible through isolated research."

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Front Cover: Navy men and electronic scientists of Operation Deep Freeze '61 set up a Grasshopper Automatic Weather Station in Antarctica. Official U. S. Navy Photograph by PH1 Jack W. Leonard. See article page 237.

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General view of Boulder area looking west. Table Mountain (elevation about 6000 ft.) is the mesa at lower left with pines ringing the flat summit. Bureau of Standards laboratories lie in center foreground. Part of Boulder (area population about 40,000) occupies right. In background are the Flatiron Mountains, a front range of the Rocky Mountains.

Land at the site will be made available by the State of Colorado without cost to the Federal Government.

Among the advantages offered by the Table Mountain location are:

—Boulder is a highly desirable location for study of hail, thunderstorms, tornados, and associated squall line phenomena.

—Boulder is a desirable location for study of jet streams and of weather in the belt of maximum westerlies, although not an appropriate location for hurricane study.

—Boulder is centrally located with respect to the distribution of research centers now engaged in atmospheric research and training. This is important because of the Center's planned function as coordinator in multi-institution investigations.

—Nearby mountainous areas produce local weather phenomena that may materially affect weather conditions throughout the Great Plains, and even more extensively over the United States. Some of these mountain effects extend up as high as 80,000 to 100,000 ft.

—High ionospheric layers and atmospheric airglow phenomena can be readily observed and studied at this site.

—Generally excellent flying conditions prevail, an advantage in accessibility of this location and in special atmospheric research projects in the area.

—Boulder is an expanding research center with a hospitable scientific environment.

Purpose of the National Center for Atmospheric Research is to assist universities and other research institutions, through cooperative basic research, to increase our knowledge and understanding of the atmosphere and the physical processes that govern its behavior. The Center will, as its programs mature, be particularly concerned with fundamental studies on a plenetary scale.

The U-2 as an Instrumented Aircraft for Geophysical Research

ROBERT M. RADOS, *Chief Experimental Meteorology Branch, Meteorological Development Laboratory, Geophysics Research Directorate, U.S. Air Force, Bedford, Mass.*

DURING recent years, the Geophysics Research Directorate of the Air Force Cambridge Research Laboratories has used a number of aircraft to gather geophysical data needed in attacking practical and theoretical problems. Studies have been or are now being made of thermal radiation, gravity, ozone, auroral activity, arctic surveys, etc., as well as of a variety of meteorological phenomena. This article will discuss some of these studies, especially in relation to investigations being conducted using a specially-equipped Lockheed U-2 research aircraft as a data-gathering vehicle.

The present program is, of course, built upon past experience which includes the jet stream research flights of 1953–1955 and 1956–1958, the Sierra wave research flights of 1954–1955, and the hurricane research flights of 1954–1955. During these programs, the use of Doppler automatic navigation equipment to measure winds was introduced and perfected. Instrumentation also included facilities to measure and record free-air temperature, turbulence, pressure, absolute height above terrain, and to obtain cloud photographs. Calibration techniques, recording systems, and data processing procedures were gradually evolved; however, complete data processing and packaging lagged flight programs by a year or more. These programs had the advantage of using large bomber-type aircraft, both piston and jet powered, so that there was usually ample space for equipment and observers. Disadvantages of these aircraft were their high initial cost, high operating expenses, large air crews, and the scarcity of convenient operating bases.

Developments in miniaturizing equipment (particularly the Doppler auto-navigation system) and in building more versatile and compact recording systems which provide automatic data readout have continued since the early days of the studies. Moreover, instruments have been recently developed with Air Force support for measuring ozone, humidity, radiation, dust concentrations, and sky brightness. The availability of a U-2 aircraft as a controllable platform has enabled the Geophysics Research Directorate to assemble an accurate, complete, and relatively inexpensive system of obtaining all of these data. Advantages of the U-2 are its small size and maneuverability, low operating costs, need for only short runways, and ability to operate at altitudes above those of conventional aircraft.

The studies which are being conducted naturally emphasize problems of special interest to the Air Force. Meteorological studies include the statistics of wind and temperature fields, the structure of circulation patterns, cloud patterns and their relation to synoptic phenomena, and the distribution of turbulence, ozone, water vapor, and other elements of the atmosphere. Particular emphasis is being placed on a study of stratospheric humidity.

In the field of thermal radiation, the aim is to determine the infrared transmission of the atmosphere at altitudes in excess of 40,000 feet and over a range of latitudes. The spectral region of interest is the 1–15 micron region. For these studies, two spectrometers equipped with a sun seeker are being utilized.

In the study of the distribution of radioactive particles, a sampling system has been used. In particular, these studies focus on the chemical mechanism of the stratosphere, storage of debris, and its eventual downward transport through the troposphere.

In support of studies concerned with meteorological satellites and application of satellite data, the aircraft is used to obtain photographs of clouds and measurement of radiation emitted and reflected by the earth and its atmosphere. A camera and a four-channel scanning radiometer marking the

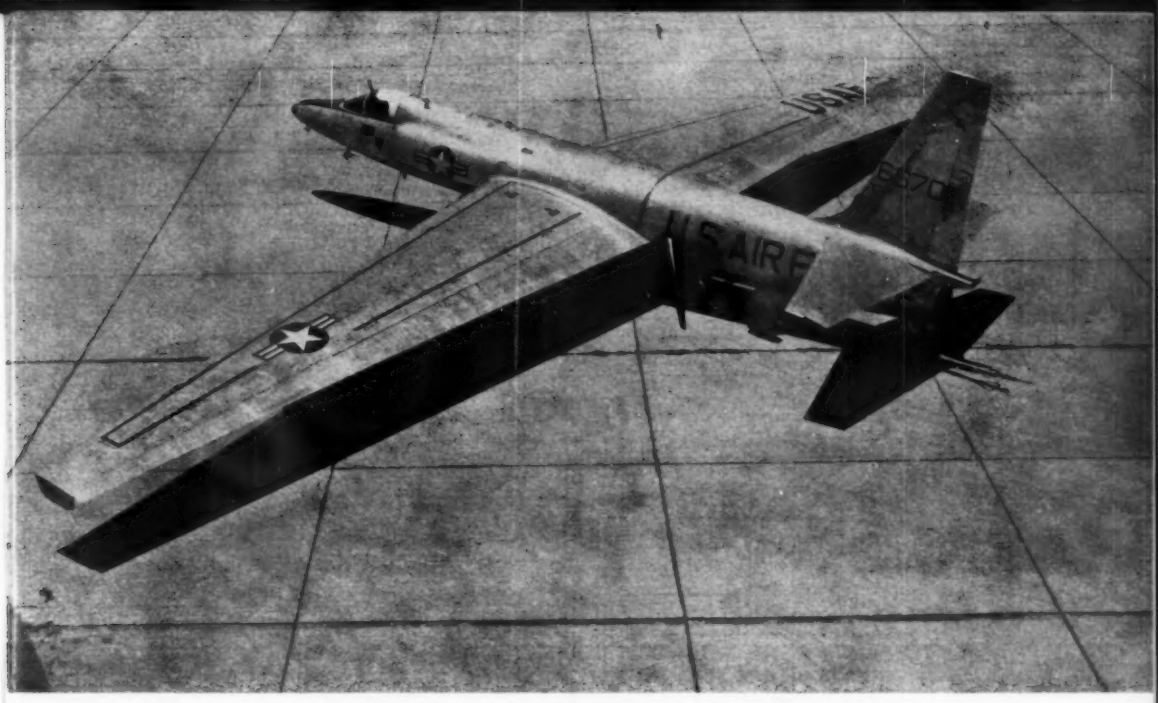


FIG. 1. A U-2 Aircraft as employed for research flights.

earth-atmosphere indicator over the range 0.2 to 4.0 microns will be used. These data will aid in the interpretation of cloud photographs taken from satellites and in relating the meteorological conditions to radiation.

In the studies of atmospheric optics, the aim is to determine how, when, where, any object—at any place and under any circumstances—could be detected in the visible or near-visible wave length.

Support to a study of interplanetary matter is being given by the collection of dust particles in the stratosphere. These samples allow for a study of: the probable hazards of interplanetary matter to high altitude missiles; the basic physics of the interaction of meteoroids with solid surfaces within the atmosphere as a means of extending the velocity range of aerodynamics into the hypersonic region; the geophysics of interplanetary particles which may have far-reaching importance in determining the role of dust on rainfall and on the heat balance of the earth.

The size and number of the instruments required to support these studies exceed the space available in the U-2 aircraft. Consequently, the instrumentation has been divided into several packages, each of which is designed to provide the complete requirements for one or a number of studies. Each package can be removed and another substituted without the need for a major change in the aircraft. The total weight of each package is less than 1000 pounds. The equipment is miniaturized and is almost completely automatic.

Figure 2 is a block diagram of the meteorological package. This diagram indicates the source of the measurement, the computers and amplifiers required, and the recording facilities. To the extreme right is a listing of the various parameters obtained by this instrument system.

The automatic navigational system provides measurements of latitude, longitude, wind speed, wind direction, ground speed, drift, heading, and true air speed. It is composed of a Doppler radar, compass, magnetic variation computer, true air speed meter, wind computer, and a dead reckoning computer. This equipment weighs about 168 pounds and measures six cubic feet. With proper calibration and attention, wind speed is accurate within about three knots and wind direction within about five degrees. The primary errors are due to the aircraft flight

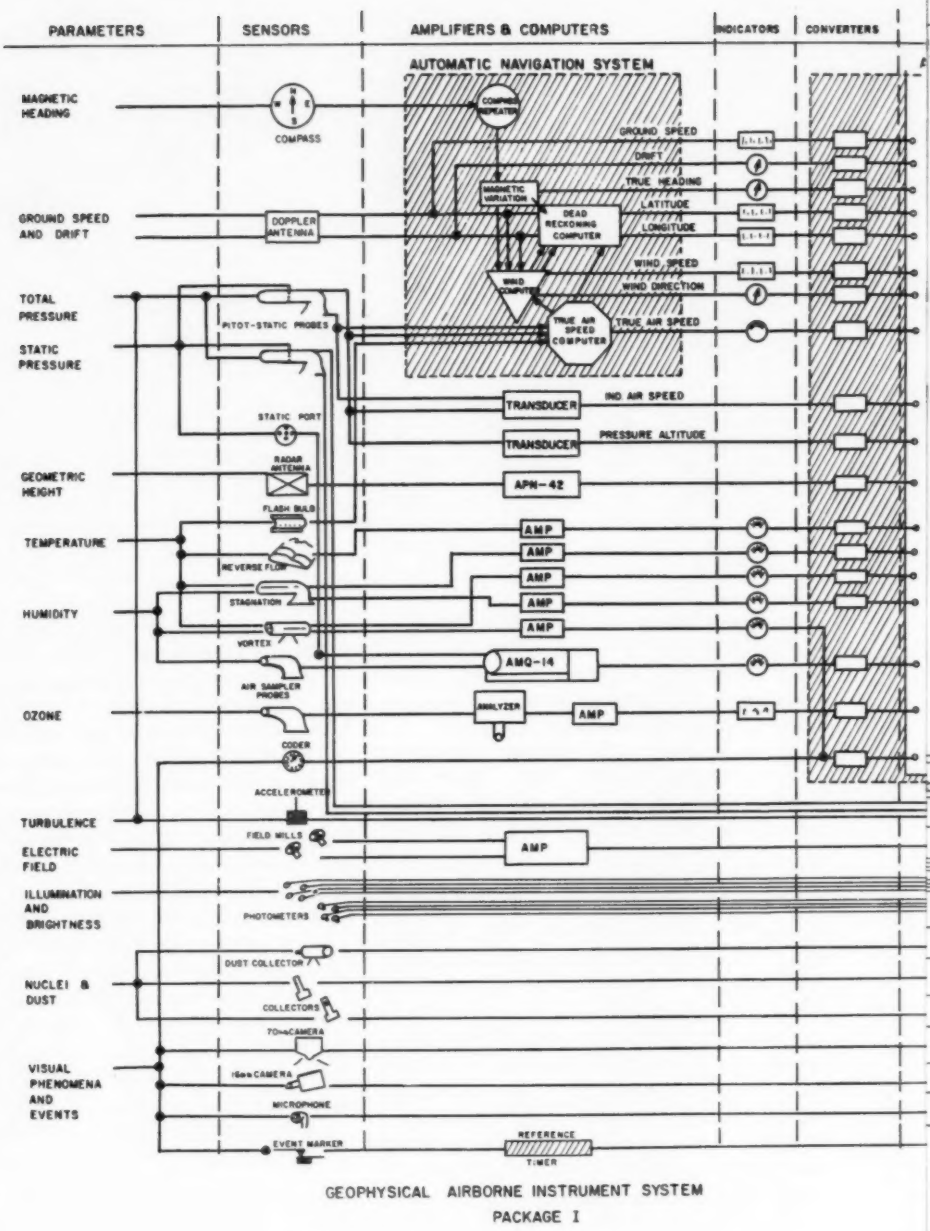
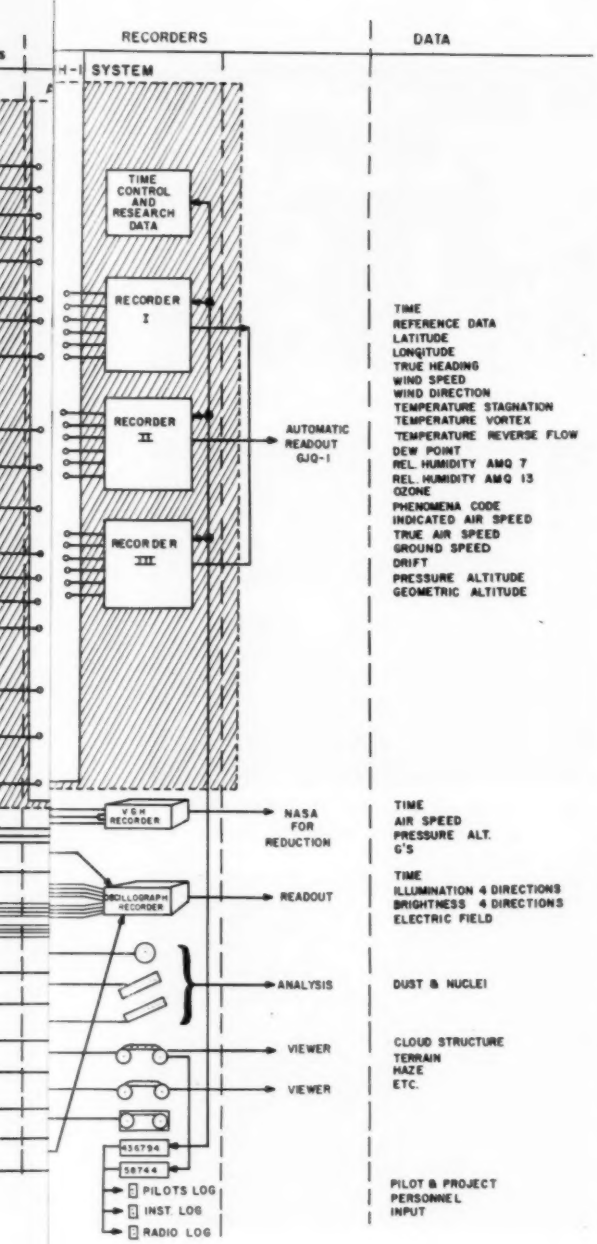


FIG. 2. GEOPHYSICAL AIRBORNE INSTRUMENT PACKAGE—PACKAGE I.



characteristics at high speed and at high altitudes.

Static (ambient) pressure and total (static plus differential pressure produced by the motion of the aircraft) are sensed, using two separate pitot-static systems. Transducers (which weigh about ten pounds) are employed to record indicated air speed and pressure altitude. The inputs of pressure altitude (PA) and indicated air speed (IAS) required by the True Air Speed meter are taken from this same system. The accuracy of PA and IAS measurements depends upon the location of the static ports. With proper ground and air calibration, PA can be measured within two millibars, and IAS within two knots.

An APN-42 radar altimeter will be used to measure geometric height above underlying surface; however, this instrument is not yet operational.

Temperature is measured by four sensors: one, a flush-bulb type, is used to provide temperature to the true air speed computer. A stagnation-type probe, AN/AMQ-7, an axial flow, vortex-type probe, AN/AMQ-13, and a reverse flow probe are used for temperature measurements. All three are used to insure accurate temperature measurements under various conditions. With proper ground and air calibrations, these thermometers will provide absolute temperature measurements within one degree of each other. Gradients or changes are accurate to tenths of a degree.

Humidity is being measured with an infrared hygrometer which employs a small computer to indicate results in terms of dew-point. To date, the instrument has not been operationally tested, but preliminary tests indicate it will be successful. The AMQ-7 and AMQ-13 sets measure relative humidity, utilizing carbon strip-type sensors. However, these are ineffective above 25,000 or 30,000 feet.

Two types of ozone analyzers have been successfully flown on a KC-135. One is the Regener chemical type; the other is a unit produced by Armour Research Foundation. The latter unit consists of two thermistors, one of which is chemically treated. The difference in temperature caused by the destruction of ozone near the treated element is a measure of the amount of ozone. One of these, or a third type being developed by Professor Regener, will be used depending upon the results of tests in the U-2.

The photometers used to measure illumination and brightness are mounted in pairs on the top, bottom, and sides of the aircraft. Narrow angle (20°) photometers are used for measuring brightness, and wide angle (180°) are used for illumination.

Figure 3 is a picture of a meteoric dust collector used in the past. When the aircraft has reached flight level, a cover is removed, and air passes through the instrument depositing the dust on a millipore filter whose contents are later analyzed in a laboratory. Improved instruments are now installed which periscope a calibrated cylinder from the top of the aircraft, see figure 4. These instruments will collect samples of dust found in the atmosphere which not only can be analyzed for chemical composition but also for concentration and distribution in the atmosphere.

Turbulence is being measured through the use of NASA VGH meters. Electric field is sensed by two field mills. A 16mm time-lapse camera and a 70mm camera are used to film visual phenomena, such as clouds (figures 7 and 8). In addition, a tape recorder and a weather coder are installed for recording the pilot's information and observations.

The recording system primarily consists of an AJH-1 recording system, a NASA VGH recorder for turbulence, and an oscillograph recorder for the photometer and electric field mill outputs. The AJH-1 system provides time and a synchronous signal to other recorders. It also provides a signal which operates a sequence counter in the cockpit used by the pilot to synchronize visual observations. The record of this system can be visually scrutinized for preliminary evaluation. Not only are trends recognizable, but actual values can be determined by totaling the marks in each column which represent a digit of a measured parameter; e.g., just below the line inscribed on figure 6, the value of the indicated air speed is 128. Time and reference data are repeated each 60 printings. Data can be recorded at various intervals up to 30 seconds. For detailed post-flight evaluation, a GJQ-1 reader is available for automatic readout of all recorded data in the form of teletype tape, IBM cards, and tabulation by an electric typewriter.

Figure 5 shows the temperature and pitot probes mounted in the skin of the aircraft; also visible is the radome for the Doppler radar.

(*Continued on page 268*)

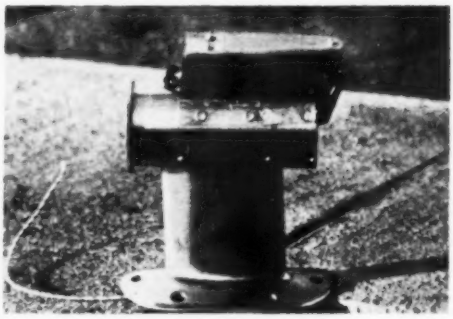


FIG. 3. The Meteoric Dust Collector.

FIG. 4. Improved cylindrical dust collector shown installed and exposed in nose of aircraft.

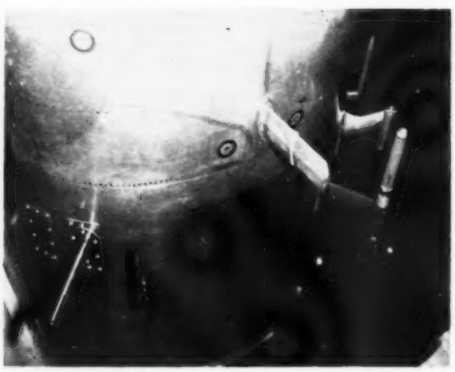


FIG. 5. Underside of aircraft showing probes. From left to right: reverse flow, pitot static, radio antenna, stagnation type temp., vortex type temp., pitot static, and radome for doppler radar shown as honeycombed area at right center.

Grasshoppers in Antarctica

TWO portable, automatic weather stations —known as Grasshoppers—have been installed in Antarctica and are already broadcasting current weather data to U. S. Navy meteorologists of Operation Deep Freeze 1961. The first was installed on the Ross Ice Shelf, and the second is in operation at the foot of Beardmore Glacier. Four more installations of automatic stations are planned for the 1960–61 season: one more Grasshopper and three new "pinball machine" Ice Stations.

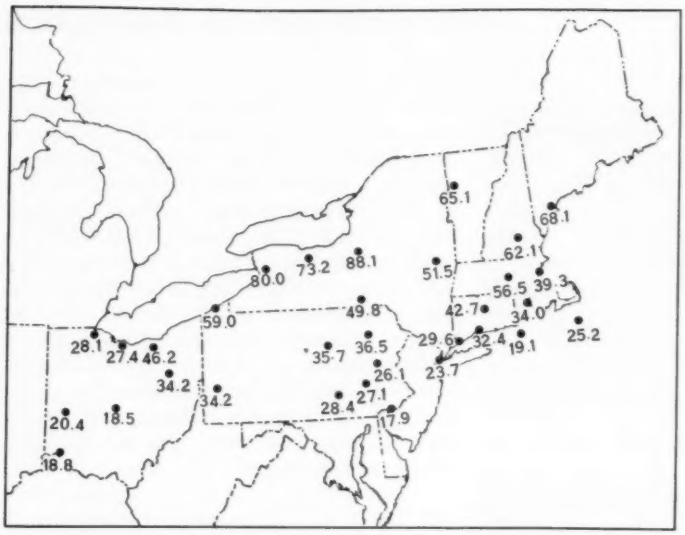
The concept of the Grasshopper grew out of the needs of World War II. An aircraft was to parachute the automatic weather station to a desired location. Once on the ground, a timer set off an explosive cap releasing five spring legs, causing the station to jump into the air in an upright position—hence the name Grasshopper. The needs of the IGY program and Operation Deep Freeze caused a revival of interest in this device and its recent perfection as an operational unit.

The Grasshopper, weighing about 280 pounds, stands 3.5 feet high when installed. A 14-foot antenna, anemometer, wind vane, and temperature unit project from the top of its cylindrical body. It is battery-powered with its mechanism governed by a clock similar to those used in automobiles. The clock turns the station on at a preset time. The machinery then selects the information to be relayed, the transmitter is activated, and the station delivers its message.

The station first identifies itself and then describes the air temperature, wind direction, wind speed, and barometric pressure. The first letter in each three-letter Morse code group announces which element of the weather will be described, and the last two letters describe its condition. The present Grasshopper is capable of transmitting a distance of 400 miles for a duration of two to three months and up to five months with double battery power.

The new Ice Stations will be equipped with a device known as a "pinball machine" and are designed to be more accurate and more reliable. Of about the same weight as the Grasshopper, they are mounted on a six-foot sled and can be hauled into position by land transportation. The Ice Station will be able to transmit a distance of 800 miles on two frequencies for an unattended period of three months. The more sophisticated "pinball mechanism" will allow aerologists to activate the machine and to receive weather broadcasts at any time.

Navy men and electronic scientists of Operation Deep Freeze '61 set up a Grasshopper Automatic Weather Station at the foot of Beardmore Glacier in the Antarctic. Leroy M. Allison, Jr. and Paul R. Wick, ET2, USN, setting up the Grasshopper. Official U. S. Navy Photograph by PH1 Jack W. Leonard.



Station used to prepare averages given in Table 1, and their normal annual snowfall in inches.

Snowfall Over Eastern United States: Factors Leading to Its Monthly and Seasonal Variations*

JEROME NAMIAS, *U. S. Weather Bureau, Washington, D.C.*

INTRODUCTION

THE large variations in snowfall which occur among winters have posed a problem of utmost complexity to meteorologists. It is probably not an exaggeration to say that the meteorological profession looks upon abnormally snowy and relatively snowless winters in any area as *curiosa* in just about the same way as the layman. Yet these year-to-year variations must have a physical explanation, for they are manifestations of short-period climatic fluctuations just as periods of drought, flood, and increased vulnerability to hurricanes. Inasmuch as some weather abnormalities of this nature have been shown to be related to the prevailing large-scale (or planetary) upper-air wind systems of the Northern Hemisphere,[1] a similar though preliminary attempt is made in this paper to investigate the snow characteristics of winters in northeastern United States. This type of study is a necessary prelude to any rational attempt to predict the character of winter.

SOURCES OF MATERIAL

There are two primary sources of data used in this investigation: (1) snowfall totals for many stations in northeastern United States and (2) seasonally averaged or mean maps at the 700 mb (about 10,000 foot) level. The latter charts have been worked up for the four seasons since 1932, considering winter as the three months December, January, and February. Owing to the availability of these charts, winter snowfall statistics were also worked up for these periods.

The northeastern cities whose records were conveniently available for these purposes are shown in figure 1, together with the normal annual snowfall.

* This paper was presented at the Annual Meeting of the Eastern Snow Conference in February 1960 and published in the proceedings. To give this interesting subject a wider circulation among meteorologists, it is being presented in full to *Weatherwise* readers.

TABLE 1

AVERAGE SNOW RECORDED AT 32 STATIONS OVER NORTHEASTERN U. S. FOR WINTERS 1929 THROUGH 1959

Rank	December		Dep. from 30-yr. avg.	January		Dep. from 30-yr. avg.	February		Dep. from 30-yr. avg.	Cold season total		Dep. from 30-yr. avg.
	Year	Avg.		Year	Avg.		Year	Avg.		Year	Avg.	
1	45–46	17.4	+9.5	44–45	21.1	+10.8	33–34	20.1	+10.3	55–56	58.3	+17.7
2	44–45	16.0	+8.1	47–48	19.6	+ 9.3	57–58	20.1	+10.3	57–58	56.4	+15.8
3	51–52	15.8	+7.9	34–35	16.4	+ 6.1	39–40	16.6	+ 6.8	44–45	55.3	+14.7
4	33–34	12.4	+4.5	35–36	15.9	+ 5.6	46–47	15.9	+ 6.1	47–48	53.5	+12.9
5	47–48	12.3	+4.4	56–57	14.5	+ 4.2	49–50	13.7	+ 3.9	33–34	51.4	+10.8
6	29–30	11.4	+3.5	57–58	14.4	+ 4.1	44–45	12.3	+ 2.5	51–52	49.3	+ 8.7
7	56–57	11.1	+3.2	53–54	14.4	+ 4.1	51–52	12.0	+ 2.2	35–36	48.7	+ 8.1
8	50–51	11.0	+3.1	38–39	13.7	+ 3.4	32–33	12.0	+ 2.2	58–59	47.8	+ 7.2
9	35–36	10.9	+3.0	40–41	13.6	+ 3.3	35–36	11.7	+ 1.9	56–57	46.3	+ 5.7
10	42–43	10.4	+2.5	42–43	13.6	+ 3.3	43–44	11.3	+ 1.5	38–39	45.9	+ 5.3
11	48–49	9.0	+1.1	58–59	12.3	+ 2.0	47–48	11.2	+ 1.4	50–51	44.2	+ 3.6
12	58–59	8.6	+0.7	50–51	11.0	+ 0.7	34–35	11.1	+ 1.3	40–41	44.1	+ 3.5
13	54–55	8.0	+0.1	37–38	10.9	+ 0.6	45–46	11.0	+ 1.2	39–40	42.6	+ 2.0
14	46–47	8.0	+0.1	55–56	10.2	− 0.1	55–56	10.2	+ 0.4	42–43	42.6	+ 2.0
15	55–56	7.6	−0.3	48–49	9.7	− 0.6	41–42	9.5	− 0.3	46–47	41.4	+ 0.8
16	30–31	7.0	−0.9	39–40	9.2	− 1.1	54–55	9.1	− 0.7	45–46	41.1	+ 0.5
17	32–33	6.7	−1.2	30–31	9.0	− 1.3	38–39	8.0	− 1.8	34–35	39.1	− 1.5
18	52–53	5.9	−2.0	51–52	8.6	− 1.7	31–32	7.6	− 2.2	49–50	37.4	− 3.2
19	37–38	5.5	−2.4	52–53	8.6	− 1.7	48–49	6.8	− 3.0	53–54	36.4	− 4.2
20	39–40	5.4	−2.5	41–42	8.1	− 2.2	58–59	6.8	− 3.0	48–49	33.9	− 6.7
21	57–58	5.1	−2.8	29–30	7.5	− 2.8	50–51	6.8	− 3.0	54–55	33.9	− 6.7
22	34–35	5.1	−2.8	45–46	7.4	− 2.9	42–43	6.7	− 3.1	30–31	32.8	− 7.8
23	49–50	4.7	−3.2	46–47	7.2	− 3.1	30–31	6.4	− 3.4	43–44	32.5	− 8.1
24	38–39	4.4	−3.5	54–55	5.9	− 4.4	52–53	6.3	− 3.5	32–33	30.9	− 9.7
25	40–41	4.3	−3.6	49–50	5.3	− 5.0	40–41	6.2	− 3.6	41–42	30.4	−10.2
26	36–37	3.9	−4.0	36–37	5.1	− 5.2	53–54	5.9	− 3.9	29–30	30.1	−10.5
27	53–54	3.7	−4.2	43–44	4.7	− 5.6	37–38	5.2	− 4.6	37–38	29.7	−10.9
28	41–42	2.7	−5.2	33–34	3.8	− 6.5	29–30	5.1	− 4.7	36–37	27.7	−12.9
29	43–44	2.0	−5.9	31–32	3.6	− 6.7	56–57	4.6	− 5.2	52–53	27.5	−13.1
30	31–32	1.1	−6.8	32–33	2.5	− 7.8	36–37	3.8	− 6.0	31–32	26.2	−14.4

The December, January, and February snowfalls for individual years from 1929 through 1959 for these stations were then tabulated, summed, and averaged for the area, and the resulting average snowfalls were ranked in descending order, as shown in Table 1. Thus the winter of greatest average snowfall for this period was 1955–56 when 58.3″ was observed (17.7″ above the 30-year areal average) while the winter of least snowfall was 1931–32 when an average of only 26.2″ was recorded (14.4″ below average). A rough idea of the economic importance of this difference may be obtained by estimating the difference in total weight of the snow over this area in the snowiest and in the least snowy year. These estimates are approximately 70,000 compared to 30,000 megatons.

A sample of the upper-air maps used in this study is given in figure 2, where the solid lines represent contours of the 700 mb pressure surface, and the broken lines departures from long-term normals. In interpreting these maps the reader should bear in mind that the resultant wind blows parallel to the contours so that lower heights lie to the left of an observer facing downwind. The isopleths of departures from normal (broken lines) represent the *anomalous component* of the resultant wind. The relationship of this component to the broken lines is the same as that expressed above for the total wind related to the solid lines.

We shall now examine some of the high and low ranking snow years of table 1 in the light of the corresponding charts.

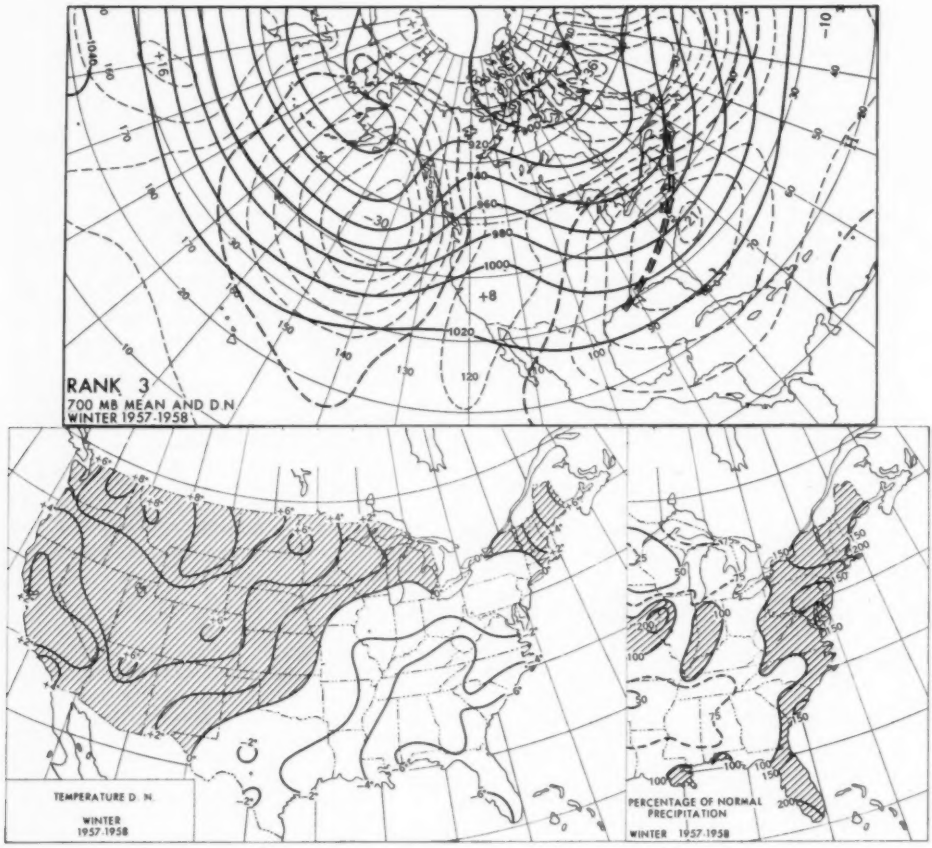


FIG. 2. UPPER: Mean 700mb contours (solid lines labeled in tens of feet) for winter 1957–58, and isopleths of departure from normal (broken) drawn for each 50 feet and with maximum values labeled in centers. Arrows denote principal track of storms.
LOWER LEFT: Associated isopleths of departures from normal of temperature F°.
LOWER RIGHT: Percentage of normal precipitation.

PATTERNS ASSOCIATED WITH LIGHT AND HEAVY SNOW YEARS

When the mean flow charts for years of heavy and light snows are examined, it becomes clear that there are appreciable differences. This does not mean that a unique pattern of prevailing upper-air flow is observed for each category of snowfall, for snowstorms come in strange varieties. However, the charts associated with the six highest and six lowest ranks of table 1 suggest fundamental types of anomalous flow which indicate the abnormality of the snow regime. At first this correlation may not appear too surprising until it is realized that snow-storms are capricious and occur only a small number of days of the 90 making up the seasonal mean maps. Obviously, it would not be feasible to reproduce all the seasonal mean upper-air maps studied in this report; therefore only a few winter circulation patterns favoring heavy or light snow years will be shown. Unfortunately (and perhaps surprisingly), in the heaviest snow year, 1955–56, most of the snow occurred during the month of March, and therefore we cannot relate this to our

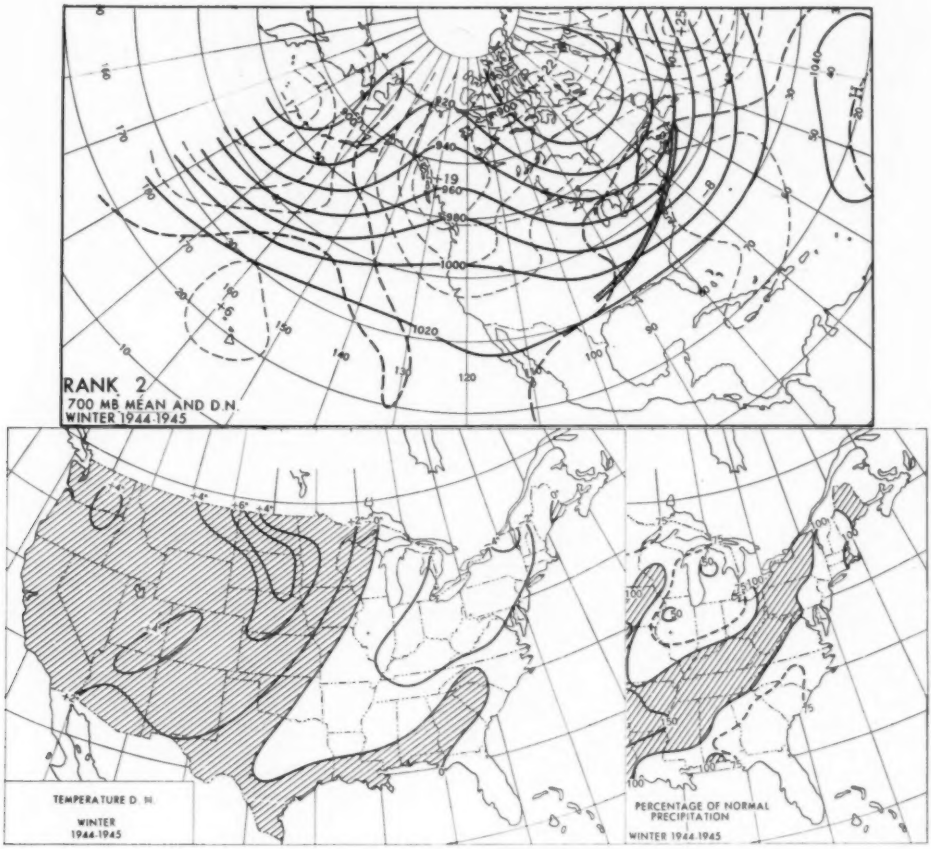


FIG. 3. WINTER OF 1944–45. Charts show 700mb contours, temperature departure from normal, and percentage of normal precipitation.

seasonal charts for winter (December, January and February). This peculiarity is indicated by noting the respective ranking of the winter months of 1955–56 in Table 1 (Rank 15 in December and February and Rank 14 in January). This case in itself is adequate evidence that snows are not confined to the months popularly associated with winter.

The winters 1957–58 and 1944–45, which rank 2 and 3, respectively, are quite typical for patterns making possible heavy snowstorms. The outstanding features of these charts (figs. 2 and 3) are (1) strong positive anomalies in the 700 mb contour patterns over much of Canada and adjacent portions of the Atlantic, (2) a stronger than normal trough over eastern United States and strong ridge over the Far West. These conditions represent weaker than normal westerly winds over much of the continent (low zonal index), the deployment of colder than normal air masses over eastern United States, and the generation and steering of southern storms northeastward along the eastern seaboard. The accompanying departures of temperature are shown below the mean contour charts, and the prevailing (principal) storm tracks for the season are indicated by arrows superimposed on the contour charts. The accompanying departures of precipitation, to the right of the temperature anomalies, show that precipitation was not extremely heavy over most of the

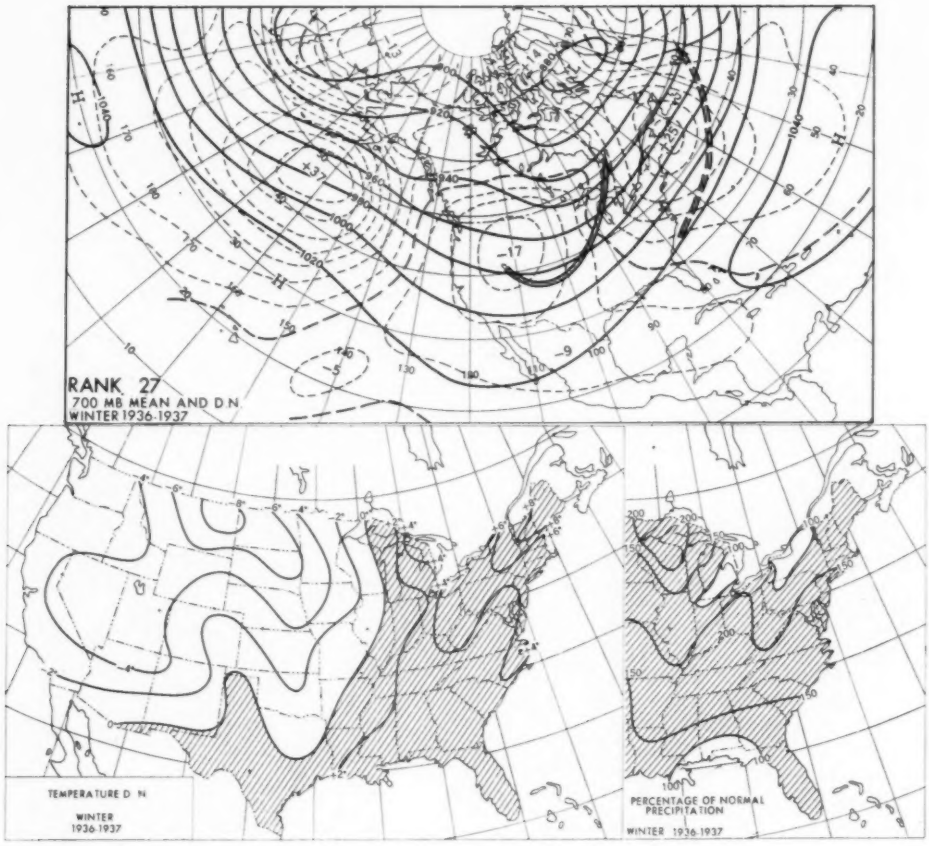


FIG. 4. WINTER OF 1936–37. Charts show 700mb contours, temperature departure from normal, and percentage of normal precipitation.

area, so that much of it was in the form of snow rather than rain. This was due in large part to the cold air masses prevailingly deployed in the anomalous patterns of upper-air flow.

The impression one obtains through study of many charts such as these and related material, is that an anomalous upper-level wind pattern becomes established for the winter and persistently recurs in similar form with only brief and transitory deviations. These anomalous wind patterns to a large extent set the stage for certain types of storm development in particular areas, and moreover, because of their ability to deploy warm or cold (and wet or dry) air masses into the storm areas, determine the growth rate of the storm once formed. The course of the storms is also frequently determined by these quasi-stable wind patterns, which in effect steer them. Thus the central problem involved in winter snow characteristics, and indeed in all other types of climatic fluctuations, must involve the prevailing wind patterns of the general circulation of the atmosphere. We shall not attempt to discuss this basic phase of the problem in this brief paper, but only mention that it still remains unsolved.

If now we look into the relatively snowless years, the lowest ranks of Table 1, we find strikingly different patterns than for the heavy snow years.

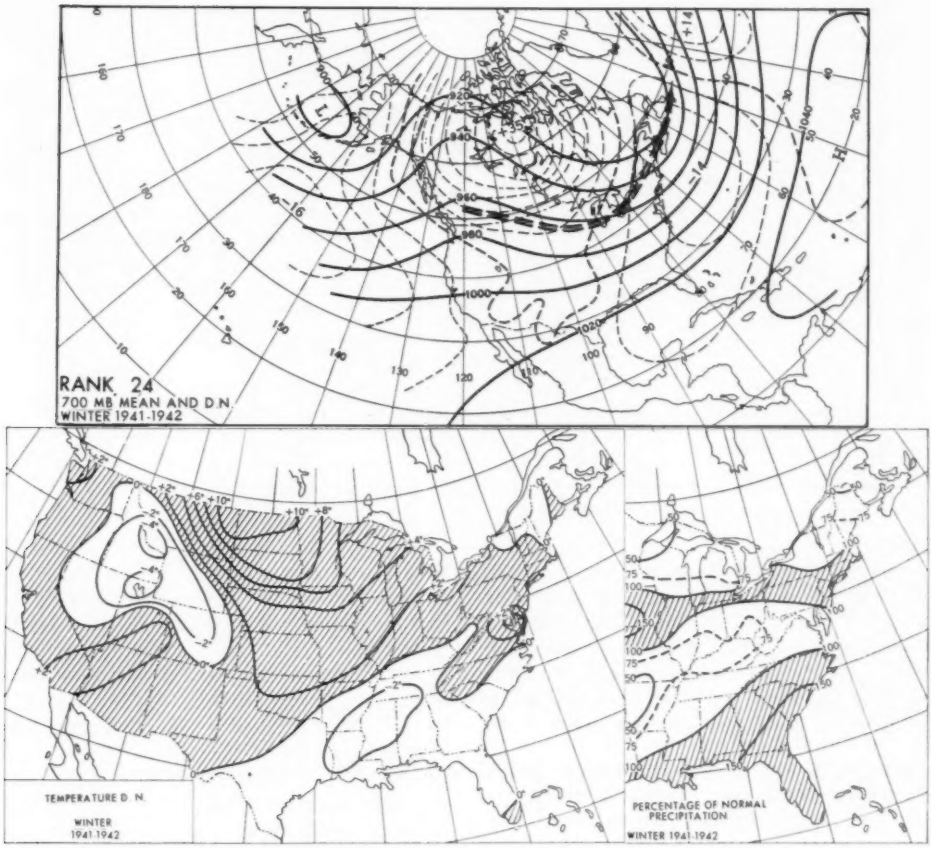


FIG. 5. WINTER OF 1941–42. Charts show 700mb contours, temperature departures from normal, and percentage of normal precipitation.

One of the typical examples is afforded by the winter 1936–37, depicted by the charts reproduced in figure 4. The most noteworthy feature is the anomalously strong trough over the far west flanked by strong ridges over the adjacent Atlantic and Pacific. This prevailing wind pattern results in warm temperatures over eastern U. S. and cold weather in the west—an ideal situation for strong development and northward movement through the east-central portion of the country. These storms deposit copious amounts of precipitation (see percentage of normal precipitation chart in fig. 4), but owing to the enhanced flow of warm air from the south (relative to normal), precipitation over the northeast occurs mostly in the form of rain rather than snow. In other words, although these cases include strong storm-generating and developing mechanisms, the air masses injected into the storms are generally too warm to produce heavy snows in the northeast.

Obviously, years with abnormally light snow may also occur when the total precipitation (both rain and snow) for the winter is low. A common case of this kind (winter 1941–42) is shown in figure 5, where the negative anomaly off the East Coast is not surmounted by large positive anomalies as was the case in figures 2 and 3 (heavy snow years). Thus the large-scale anomalous component of flow from the Atlantic, important for northeastern precipitation, was largely absent and replaced by drier air from con-

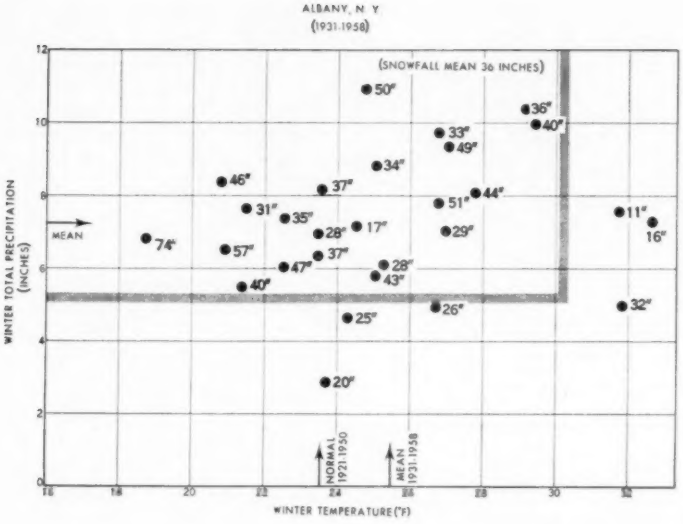


FIG. 6. Winter snowfall in inches at Albany, N. Y., as a function of winter temperature and total precipitation.

tinental sources in Canada. On the other hand in the wet snow years, like those illustrated in figures 2 and 3, East Coast cyclones appear to be diverted northward rather than eastward or become stalled by great blocking anticyclones which are other manifestations of the positive anomalies in northeastern Canada.

SEASONAL SNOW AMOUNTS IN RELATION TO MEAN TEMPERATURE AND PRECIPITATION

In the foregoing section the large-scale nature of wind-patterns and related air mass interactions which help determine the winter snow picture for the Northeast was described. It is also of interest to select one station and try to relate the winter snowfall to the two elements mean temperature and total precipitation. This has been done for Albany, N. Y., as shown in figure 6, where snow amount has been plotted against mean winter temperature and total precipitation. Outside the boxed-in area are six years with subnormal snowfall. The three to the far right indicate that although there was ample total precipitation (about normal) the temperatures were too warm. Of course, the temperatures during individual storms differ from the seasonal mean, and were probably still warmer. The three values below the boxed-in area are cases when the total precipitation was so low that even if it were mostly in the form of snow the total depth recorded would not be high. In general, however, it is seen that there is rather poor relationship between mean seasonal temperature, total precipitation, and snow amount. The one portion of the graph indicating such a relationship is the area bounded by horizontal 6″ and 8″ lines for total precipitation, where the total snow amounts appear to increase fairly regularly with decreasing mean seasonal temperature. Part of this increase may be due to the lesser density of snow at low temperatures, as well as, more obviously, the less frequent occurrence of rains under these circumstances. Then again, one must consider the "feed-back" of increased snow on the temperature of the overlying air. That is, heavy and more persistent snow accumulations naturally help to reduce air temperatures, both because of the greater albedo of snow and the heat required to melt or sublimate it.

The overall lack of clear-cut organization of points in the graph points up the need for considering the large-scale factors (wind patterns, storm tracks, and air mass interactions) for a more complete understanding of winter snows.

LONGTERM VARIATIONS IN ANNUAL SNOWFALL

It is well recognized that climatic fluctuations take place on many time scales: not only

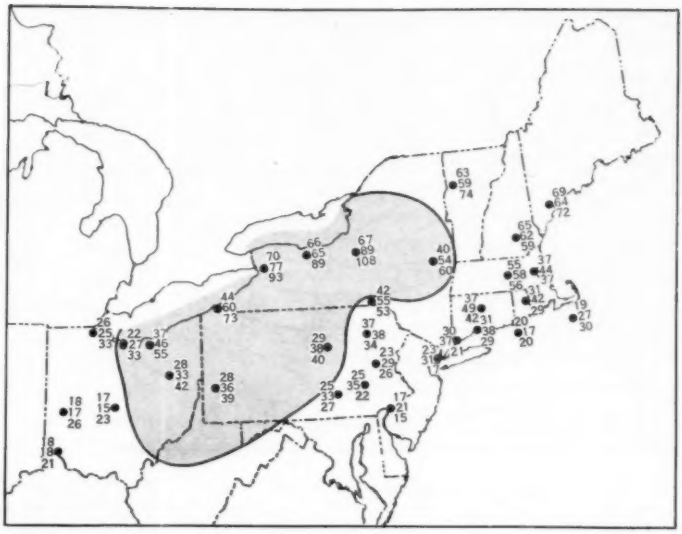


FIG. 7. Average cold season snowfall in inches for successive decades: 1929–30 to 1938–39 (top value); 1939–40 to 1948–49 (middle); and 1949–50 to 1958–59 (bottom). Shaded portion indicates area of general steady increase.

from year to year, but from decade to decade, century to century, and up to epochs of geological time. Although the data used for this study are necessarily restricted to the winters from 1929–30 to 1958–59, they provide interesting information about fluctuations for the past three decades. Average annual snowfalls for three consecutive ten-year periods beginning with 1929–30 are plotted in figure 7. In the shaded area, except for Rochester, there has been a gradual increase in recorded snowfall from the 1930's to the 1940's and 1950's. On the other hand over most stations to the east of the shaded area a decrease set in especially from the decade of the 1940's to the 1950's.

Appreciable light on the reasons for this decadal variation is shed by composite (average) charts for the winters of the latter two decades. These are shown in figures 8 and 9, and the change between these is shown in figure 10. It is clear that the large-scale prevailing wind patterns of the upper air were appreciably different between the two decades, and we shall attempt to explain why these changes favor an increase in snow over the shaded area in fig. 7, but a decrease in the area to the east. In the 1940's the negative anomaly off the East Coast and the anomalous northerly components of flow over the entire Northeast favor diminished precipitation. In the winter of the 1950's on the other hand, the anomalous flow is from the southeast over much of the concerned area. The map of difference between decades (fig. 10) brings into sharp focus the greater southeast drift of the 1950's relative to the 1940's. This anomalous drift indicates a greater prevalence of warm maritime air and air flow from the south in the latter decade. This condition favors increased warmth, increased moisture, and conduciveness to vertical ascent favoring precipitation. The increased warmth of the 1950's relative to the 1940's over the Northeast is indeed demonstrated in figure 11.

Especially over areas east of the Appalachians, this greater maritimity was apparently enough to raise the temperature during storms so that a large portion of the precipitation fell as rain rather than snow. Farther west, however, in areas of greater continentality where normal temperatures are lower, and where there is a diminished effect of warming due to increased maritimity, the increase in precipitation would naturally be more apt to occur in the form of snow. Here we have an example of opposite effects on the snow picture introduced in adjacent large areas by a still larger-scale phenomenon of the general atmospheric circulation.

In figure 9 one should also note the lesser intensity of the ridge over western United

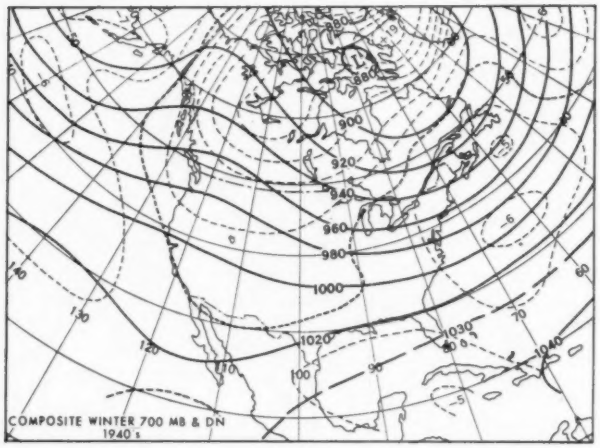


FIG. 8. Composite (average) 700mb contours (labeled in tens of feet) and isopleths of departure from normal (drawn for each 50 feet, with centers labeled) for winters of 1940–49.

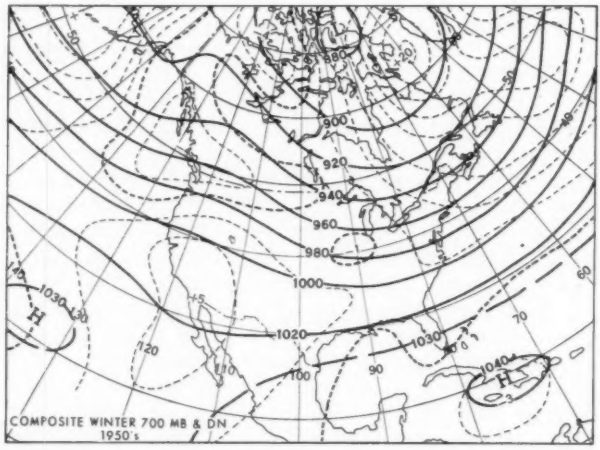


FIG. 9. Composite charts for winters 1950–59.

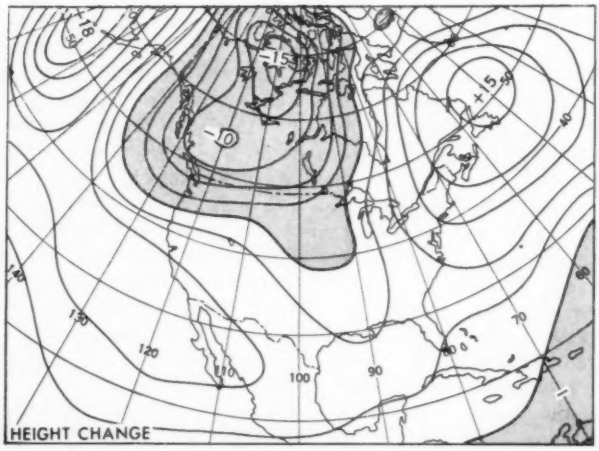


FIG. 10. Change in contour height (chart for 1950–59 minus 1940–49).

States in the latter decade (associated with the large falls in height in fig. 10), indicating greater prevalence of the "Alberta type" cyclones which usually influence the Northeast. Thus this increased cyclonic activity would also favor the 1950's relative to the 1940's as a snowier decade in the shaded area, but not to the east where greater maritimity prevailed.

SUMMARY

Variations in annual snowfall over northeastern United States are associated and probably dependent upon the average patterns of the general atmospheric circulation in the vicinity of North America and adjacent portions of the neighboring oceans. These patterns influence the life history of storms, including their regions of genesis and path, in part by injecting air masses of differing properties in differing locations from year to year. These factors largely determine the snow picture.

These large-scale variations in wind pattern, highly germane to an understanding of annual variations in snowfall, give greater meaning to simple analyses of averages of elements associated with varying seasonal snowfalls at one station.

Even when averaged over decades there are large variations in average snowfall. These, as well as inter-annual variations, appear to be highly correlated with the average mid-tropospheric prevailing wind pictures.

A special analysis of conditions during the 1940's and 1950's reveals a large area of increased snowfall from the eastern Great Lakes to the Appalachians and a general decrease east of here. These differences are associated with large-scale difference in the mean upper wind circulation between decades favoring increased maritimity and warmth in the 1950's but operating in such a manner as to increase snowfall well inland yet decrease it along the Atlantic Seaboard.

ACKNOWLEDGMENT

The author wishes to express thanks to Mr. James F. O'Connor for assisting in the preparation of the data used in this article and for making suggestions leading to improvement in the manuscript.

[1] A detailed account of these problems will be found in "30-day Forecasting—A Review of a Ten Year Experiment" by the author, published as Vol. II, No. 6, of *Meteorological Monographs* by The American Meteorological Society, Boston, Mass.

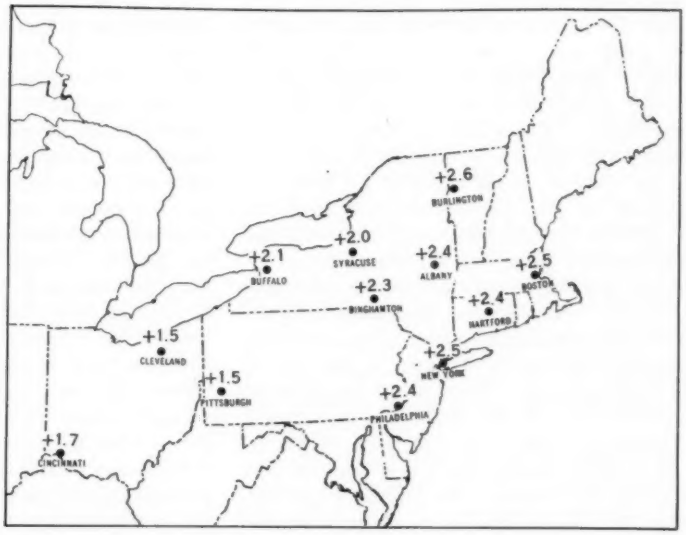


FIG. 11. Temperature change in degrees Fahrenheit from winters of the 1940's to winters of the 1950's.

The Big Snow of 1836

DAVID M. LUDLUM

THE generally accepted opinion that the climate of America was warming up, especially in winter, and that old-fashioned snowstorms were a thing of the past, received a setback in the decade of the 1830's. After a series of generally warm winters from 1822 to 1830, Old Man Winter returned to his erstwhile haunts in the Northeast. Chester Dewey, for many years professor of Natural Philosophy at Rochester Collegiate Institute, wrote at the end of the 1830's that much more snow had fallen in recent years than when the Genesee country was first settled in the early years of the century. The records of the "Meteorological Observations made at Sundry Academies in the State of New York," maintained from 1826 to 1863, reinforce Dewey's opinion. They also point to the winter of 1835–36 as the standout for long continuance of severe conditions, and mark the snowstorm of 8–10 January as the undisputed holder of the title—The Big Snow.

The first days of January 1836 were continuously cloudy in the Northeastern States with intermittent rain falling along the coastline and light snows westward to the crest of the Appalachians. A trough of low pressure hovering just off the coastline maintained a maritime circulation of cool, moist, northeasterly winds in conjunction with a blocking high over eastern Canada. On Thursday and Friday, the 7th and 8th, as an energetic coastal low moved northward in the trough, wind speed picked up to almost gale force and the drizzle turned into a steady rain. Early on Saturday morning, the 9th, the rain changed to snow at Philadelphia and New York City as the winds worked around to north and temperatures tumbled to the freezing mark.

By Sunday morning Philadelphia measured 15 inches of a slushy mess in the streets; estimates were made that about 36 inches would have piled up if the mercury had been a degree or two lower. The four days of mixed precipitation dropped an impressive total of 4.50″ in the rain gage maintained at the downtown Pennsylvania General Hospital. Over in south-central New Jersey, where the fall was estimated at two feet, millions of dollars worth of damage to timber lands resulted from the heavy, wet snow bowing and breaking tall cedars with its icy burden. The weatherman at Burlington, New Jersey, noted on the 9th: "Dreadful snow all day—snow near 20 inches deep."

At New York City the fall marked "the heaviest snow storm for several years." At Erasmus Hall in Brooklyn it measured 18 inches and in Manhattan most observers thought about 15 inches had fallen. Coastal points were buffeted by strong gales as the disturbance moved northward just offshore. At Lewes on Delaware Bay a great gale from the northeast raged on Friday putting the

Location of principal places mentioned in text.

beach awash. On Saturday night, as the storm center passed to the eastward, the gale backed into the north and northwest "and it snowed tremendously for 36 hours. A perfect hurricane existed on Sunday," according to the marine observer there. It appeared that the storm center must have stalled for many hours in the vicinity of Nantucket where the barometer remained below 29.00" for more than 24 hours, from 1800/9th to about 1800/10th, with the wind varying from east to north-northeast.

The main story of the January 1836 snowstorm, however, lay in the region of hills and lakes reaching from north-central Pennsylvania up to the foothills of the Adirondack Mountains in New York State and then eastward to the western slopes of the Green Mountains and Berkshires of western New England. In all parts of this sizable area the storm certainly deserved the appellation—The Big Snow.

The impact of the tremendous storm at a rural post in central New York has been succinctly told in the diary of a weather observer at Newfield in Tompkins County, just southwest of Ithaca. Jared Parsons, whose records have been preserved in the National Archives, wrote in his daily weather log:

Jan 8—snowed uncommonly steady all day—early in the morning the snow was 3 or 4 inches deep—at sunset it was plump 14 inches—very still and snow lies level, wind eastward, weather quite moderate.

Jan 9—wind this morning N.N.W. but light—continues to snow as steady & fast as yesterday—snow this morning is plump two feet & is very level—wind increases toward night—snow begins to fly some.

Jan 10—wind N.N.W. & blows pretty smartly—continues to snow as fast as yesterday and begins to drift considerable, but not very cold.

Jan 11—strong N.N.W. wind—snow is at least 3 feet deep, and is supposed by many to be 3½ feet.

Tompkins County lay at the western edge of the very deep snow belt. Farther east depths were estimated as high as five feet after the flakes ceased to fall. Willis Gaylord, always a careful weather-watcher and co-editor of the *Genesee Farmer,* later wrote that the snowfall in the highlands around his home in the Otisco area measured from 48 to 54 inches where left undisturbed and that in the 100-mile stretch from Little Falls to Cayuga the average was four feet. The *Cherry Valley Gazette,* noting a depth of 36 inches in the Otsego Lake area, thought the storm the greatest since 1807, but reported that "it was still more severe and of greater depth at Utica."

Utica Academy as a member of the New York Academy meteorological system had maintained weather records since 1827. Principal D. Prentice told of the storm in his annual report to the Board of Regents:

January 9—The greatest fall of snow occurred that has ever been observed in this city. It began on the evening of the 8th and continued till 4 P.M. of the 10th. It was impossible to measure the depth with accuracy, but the snow reduced to water, and measured in the rain gage, produced six inches and fifteen hundredths of an inch.

The editor of the *Utica Observer* in the first issue after the storm judged the snow depth "to be over four feet." All evidence points to the correctness of this report. The depth and weight of the snow mass produced a municipal crisis in Utica. The Mayor called an emergency meeting of the City Council to consider problems arising from the excessive snow as several roofs had already collapsed and brick walls were seen to bulge under the enormous weight. On the 15th the Council voted funds to clear the streets and added $100 for relief to be distributed to the needy poor.

A meteorological survey of available storm data indicates that the Big Snow of 1836 was typical of the behavior of heavy snows which visit the area, though in this case the amount of precipitable moisture was greater and the required air flow continued longer than in any other case which has come to the writer's attention. The meteorological record of J. L. Hendrick of Onondaga Academy at Onondaga Hollow near Syracuse, close to the center of heaviest falls, is illustrative.

The Onondaga record shows that there were two main phases to the storm. Light snow commenced falling generally throughout the area on January 8th with an easterly air flow,

METEOROLOGICAL RECORD—ONONDAGA ACADEMY—8–11 JANUARY 1836

	Sunrise	*1500*	*One Hour After Sunset*	*Remarks*
8 Jan	32° Southeast Rain-snow	32°	32° East Snow	Sleet and rain A.M. Snow P.M. Fell during P.M. and evening 15″.
9 Jan	30° East Snow	33°	28° Northwest Snow	A.M. snow 2 feet deep
10 Jan	26° West Snow	28°	28° Northwest Snow-hail	P.M. snow & sleet, or hail, approaching to rain, a little rain in the night
11 Jan	28° Northwest Snow	30°	30° Northwest Cloudy	Snow on an average about 3 feet deep

but did not become a heavy fall until that night. This would tie Phase One of the snowstorm to the coastal disturbance which reinforced the already prevailing northeasterly circulation of the past days. A long continuance of northeasterly flow brings Atlantic Ocean moisture far inland to be precipitated in often heavy quantities on the rising slopes of the Appalachian hill range. With temperatures hovering around the freezing mark, the atmosphere could carry a maximum content of moisture precipitable as snow.

Phase Two commenced with a shift of the wind through north to northwest as the coastal storm reached the vicinity of southeastern Massachusetts. In most localities in the Northeast such a shift of wind to northwest signals a tapering off of snowfall to flurries and eventually to clearing, but the unique geographical location of central New York, combining the open water of Lake Ontario and a background of low hills lying across a northwesterly flow, often sets up an intensive snow shower mechanism.

The relatively warm waters of Lake Ontario seldom, if ever, freeze all the way across even in the severest winters. As cold arctic blasts sweep down from central Canada and move across the open waters of the lake, the lower layer of the air is heated; becoming unstable it rises in turbulent gusts. When the unstable air strikes a barrier such as a low hill range, the turbulent updraft of the air column is reinforced. The rising air then cools until it can no longer hold its load of moisture; snow showers result in wintertime. As long as the flow of air from a northerly quadrant continues, the snow shower mechanism will continue to function.

From the data at Onondaga Hollow it will be seen that Phase One lasted about 24 hours during which two feet of snow were deposited. Then Phase Two took over on the afternoon of the 9th and continued the snowfall for 36 hours more to drop an additional 12 inches. In some more favorably located areas the amounts were even greater in this phase.

A Phase Three often accompanies a central New York storm when the following high pressure area remains poised over the upper Great Lakes and continues to rush cold air in windy gusts into the area. Blizzard conditions with blowing snow and rapidly dropping temperatures keep all indoors but the hardy and often nullify efforts of highway departments to keep roads open. In January 1836 this phase proved less troublesome than usual since the snow was too heavy for excessive drifting. It is believed that the vast circulation aloft around the Atlantic low brought warm air in from the ocean to keep temperatures aloft and at the surface close to the freezing level throughout the storm period.

The snow canopy extended westward to Rochester where it was thought that 36 inches had fallen, but the mild temperatures reduced the cover to a solid pack of 18 inches at the end of the fall. Twelve inches were reported at Lockport, but Buffalo was too far west to be affected by the Atlantic coastal storm and the northerly wind flow there was not conducive to lee-shore snow showers, so only a trace fell during these days at that often-snowy spot at the east end of Lake Erie.

To the east the snowfall reached into the Hudson Valley where Albany had 24 inches and the city of Hudson, 25 miles to the south, reported 30 inches. In the mountains along the central Hudson Valley, the *Catskill Recorder* related: "The snow commenced falling on Friday evening last, and continued with little intermission until some time on Monday. It has fallen three feet deep in the region." Depths tapered off east of the Hudson Valley. Northern Vermont had only a light fall, and east of the Berkshires in Connecticut and Massachusetts the precipitation fell mainly as rain since the northeasterly circulation brought in relatively warm maritime air from the nearby ocean.

In Pennsylvania the snow appears to have been equally as deep as in central New York State. We do not have the excellent meteorological coverage that was afforded by the New York Academy system. Gaylord, however, reported that the hill country astride the New York–Pennsylvania border received some of the heaviest falls of the storm as they were well situated to partake both Phase One and Phase Two. At Montrose, Susquehanna County, in the northeast corner of the Keystone State, the editor of the *Independent Volunteer* wrote: "We are literally surrounded on all sides by mountains of snow, which peer their snow capped peaks above one another in a style quite magnificent. It might not

SNOW DEPTHS IN CENTRAL NEW YORK—11 JANUARY 1836

Onondaga Hollow: "snow depth on an average about 3 feet deep."
Hamilton: "average depth of snow 3 feet."
Cortland: "Snow has fallen about three feet deep—the greatest depth for many years."
Monroe: "two feet of snow."
Montgomery: "a severe snow storm during the night of the 8th and 9th from North—snow depth at 1800 on Jan 11 —30″."
Johnstown: "Snow during the night—14″ fell."
Madison: "Jan 12—Snow 46″ deep."
Oxford: "32 inches fell on 8, 9, 10th."
Ellisburgh: "Snow fell 2 feet deep on level."
Oneida: "It had fallen in that time to a depth of over three feet level, and in many places by drifting rose seven or eight feet."
Canajoharie: "January 10—26″ deep and very moist."
Auburn: "Snow Jan 8—8″; Jan 9—20″; Jan 10—14″; total—42″."
Albany: "3.55 inches of water measured, 21″ snow depth."
Pompey: "January 11—depth over three feet."
Schenectady: "Snow fell to depth of two feet, some say 30 inches."
Cherry Valley: "Snow three feet deep."
Rochester: "probably three feet fell, but the mild temperatures made it pack by its weight, and the whole measured when the snowing ceased about 18 inches."
Otisco: "At the conclusion of the storm, the snow was 3½ to 4 feet where it remained undisturbed."
Rome: "Snow is five feet deep on the level."
Skaneateles: "On Jan. 11, 1836—snow four feet deep."
Oneida County: "Snow fell four feet in depth."
Ithaca: "This day commenced snowing & continued at night and day without abatement until the night of the tenth. Snow fell from four to five feet deep."

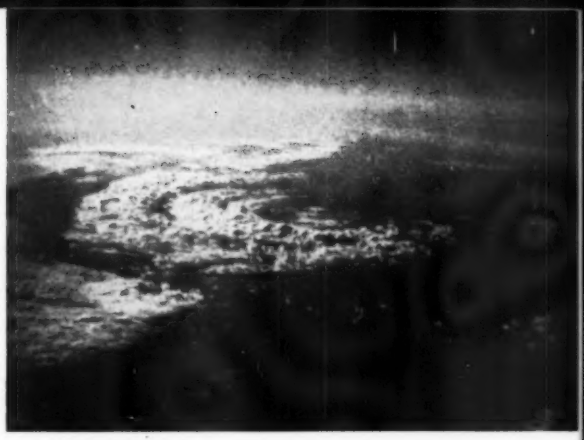
inaptly be said, that 'Alps on Alps arise', in the very center of our little village." He estimated the depth of the current storm at 42 inches, but noted that this did not equal the 54 inches which was on the ground after the Great Spring Storm of 1 April 1807.

Another very heavy snowstorm swept the interior of New York and extended well into New England on 24–25 January. Gaylord estimated that the new storm laid down an additional 36 inches of snow from Utica to central Massachusetts, and 24 inches westward from Utica to Cayuga. A third storm at the month's end increased the snow cover again: at Albany to an estimated 48 inches and at Boston to 30 inches on the 1st of February.

The deep snows of January were followed by prolonged, intense cold in February and early March. The Hudson River at New York City froze over solid so that people could cross the ice on foot to Jersey City. This had occurred only twice before in the century (1805 and 1821) and would be repeated only twice (1857 and 1875). Long Island Sound froze opposite Norwalk, Connecticut, so that it could be crossed by foot or sleigh. Boston Harbor solidified down to the Lighthouse, and Chelsea ferry had to resort to sleighs to get passengers across the Charles River. Deep Cayuga Lake in central New York froze over "for the first time in memory," as did the Lachine Rapids on the St. Lawrence River.

The following spring proved backward and the summer the coldest since 1816. Corn failed to mature in many northern locations due to the lack of warm summer nights. Snow and frost struck in late September, and by mid-October the hills of New York State were again deep in snow. In all, the year 1836 was the coldest calendar year of the century, marking the peak of the notably cold and stormy decade of the 1830's.

Bird's-eye View of a Low Pressure Center



The accompanying photograph was taken from TWA Jet Flight 801 on the evening of 8 June 1960, by TWA Navigator Alfred Weber. At the time (1944 GMT) the aircraft was at 35,000 feet altitude over 63° N, 30° W. The picture was taken with a Minnex Miniature camera looking north. The weather map for that day indicated a low pressure center in the area of the photo, and a strong west-to-east jet wind was located several hundred miles to the south.

An interesting feature of this photograph is that, due to the height of the Boeing 707 Jetliner, it was possible to observe the cloud formation swirling around the low pressure center. This is seldom possible from piston-aircraft heights, because only a portion of a system would be in view at any one time at usual aircraft altitudes.

A promise of even more complete views of cloud formations is given in preliminary information from the first weather satellite, the U. S. TIROS, which, while circling the earth at an altitude of hundreds of miles, recorded pictures enclosing several storm systems at one time. These pictures are proving to meteorologists the high degree of organization of cloud systems over the earth's surface.

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Manager of Meteorological Research
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HUMITURE DEFINED

$H = T + h$

H = Humiture
T = Temperature, of
h = Humits

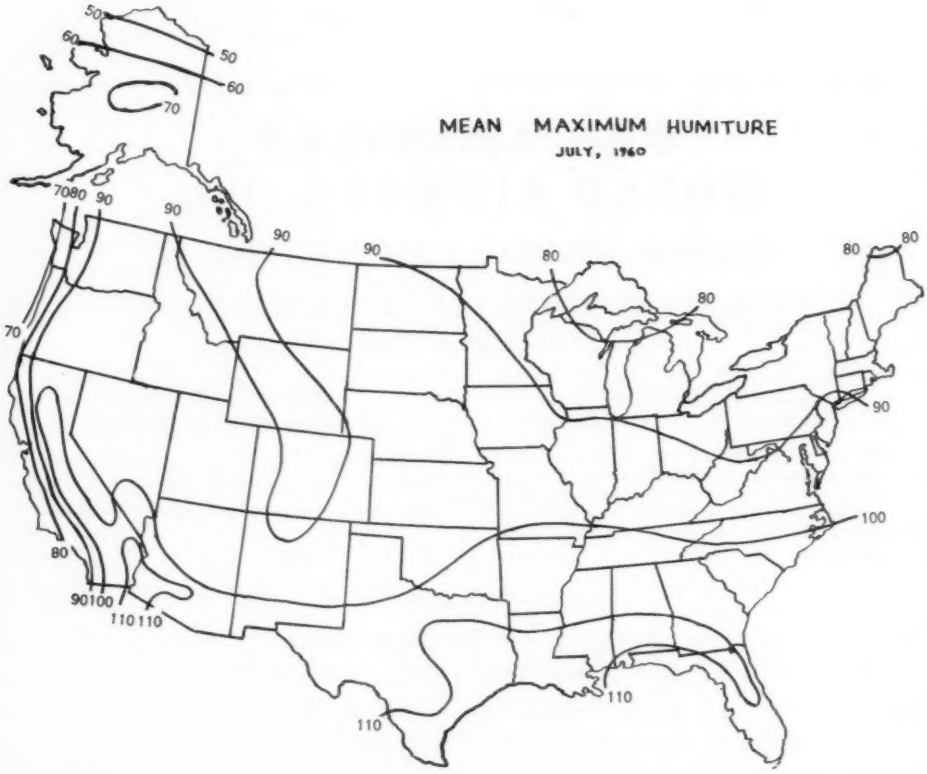
HUMITS DEFINED

$h = e - 10$

e = Vapor Pressure, MB.

Humiture Revisited

VINCENT E. LALLY AND BRUCE F. WATSON, *Tele-Dynamics Division, American Bosch Arma Corp.**



SINCE the invention of the thermometer by Galileo Galilei, mankind has noticed that comfort during periods of warm weather is not directly proportional to the temperature. For centuries, people have remarked that on warm, humid days the air feels more uncomfortable than on many a hot, dry day. Exclamations such as "Only 72 degrees but it feels like 90," often heard on warm, humid mornings, probably all but antedate Gabriel Daniel Fahrenheit.

Twenty-three years ago, Osborn Fort Heavener (1) pioneered an index to express the combined effects of temperature and moisture content on comfort. Heavener called his index "humiture." He has noted certain inconsistencies in his original definition and has enthusiastically consented to our usurping the excellent and descriptive name which he invented for his concept.

More recently, Thom (2) pointed out that a reasonably good index of comfort could be obtained through a formula which is used to gauge the effectiveness of air conditioning units under various dry and wet bulb temperatures. This index was originally dubbed the discomfort index, and later renamed the temperature-humidity index (THI). Unfortunately, the values of this index are not based on the cooling effect of evaporation from the human skin, and both are expressed in numbers that would take a long time to establish themselves as meaningful to the general public.

To overcome these problems, we propose a new index which is based on sound biometeorological principles and which is expressed in terms of a meaningful number, which, thanks to Mr. Heavener, we define as humiture.

The humiture can be defined in the following way: Assume that air of a given temperature and moisture content can be equated comfort-wise to air of a higher temperature which has a negligible moisture content. This higher temperature to which the air of a specific temperature and moisture content can be equated comfort-wise is the humiture. Humits are the units of moisture that are added to the temperature to obtain humiture. Humits are obtained by subtracting 10 from the number of millibars of vapor pressure present in the air. Humits may never be negative, however.

As examples of the above, a temperature of 90° F and a vapor pressure of 8 mbs yields zero humits and a humiture of 90, while a temperature of 90° F and a vapor pressure of 22 yield a humiture of 102. The best reason for defining humiture as an *equivalent dry-air temperature* is that this is what the public has been doing by rule-of-thumb for many years. On a humid summer morning, people often look at their thermometers in disbelief upon seeing a temperature such as 72° F. The common comment in such a case is "Only 72, but it feels like 90!". On a dry day of temperature 90° F, who has ever heard "90, but feels like 72"? In accordance with the public custom, the humiture attempts to give the figure at which air of a given temperature and moisture content "feels like" an equivalent dry temperature. Since the general public has been expressing the effects of various combinations of temperature and moisture content with reference to an equivalent dry air temperature, humiture is nothing more than an objective restatement of the index of comfort that has been used for many years. Let us examine some of the characteristics of the humiture.

a) Simplicity. The formula to obtain humiture (H) is $H = T + (e - 10)$ where T is the temperature and e is the vapor pressure.

b) Moisture content is expressed on a physical scale. The expression $e - 10$ (humits) describes water vapor in the same way that the Fahrenheit and Centigrade scales describe temperature—on a scale where reference zero is not absolute zero.

c) The units—humits—are conservative. The vapor pressure and hence the humits do not change with changes in air temperature. Further, they do not exhibit an appreciable diurnal variation as do the wet bulb and humidity. With knowledge of the morning value of humits, the man-in-the-street can approximate at any time of the day the humiture by simple addition of humits to current temperature.

d) Popular understanding and acceptance. The humiture relates to a measurement which the public has experienced—the temperature of a dry, hot day. The magic number for very uncomfortable conditions is 100 rather than the 80 to 85 THI.

There are several incidental features that

the humiture possesses that are worthy of note. For one thing, the humiture has an adequate spread—it ranges in the discomfort zone from 85 to about 135. Further, the break point at which everyone is uncomfortable is an even 100, which is easily remembered. Also, the formula is sound but simple—one need only add humits to temperature to get humiture. Since the humits will not change significantly during the day, the general public, equipped with a thermometer and a sufficient number of fingers, can add the constant humits to the ambient temperature to get humiture at any time of the day. From Table 1, humits can be obtained directly from the dew point figure by anyone who has a sling psychrometer or a dew point indicator.

TABLE 1

CONVERSION TABLE
DEW-POINT TO HUMITS

Dew-point	Humits	Dew-point	Humits	Dew-point	Humits
46	1	60	8	74	18
48	1	62	9	76	20
50	2	64	10	78	22
52	3	66	12	80	25
54	4	68	13	82	27
56	5	70	15	84	29
58	6	72	17	86	32

APPROXIMATE ZONES OF RELATIVE COMFORT

A humiture of 70–85 is considered to be in the comfort zone for most people. Note that this is the range of temperature usually found in homes in the winter. Readings in the 80's are most common in homes in which the air is very dry. Of course, the discomfort point will vary somewhat from person to person. At about 85, discomfort starts to set in for some, while at 100 everybody is uncomfortable. At 115, discomfort is at the point at which labor must be restricted. Figure 1 shows the mean maximum humiture for the United States in July 1960.

HUMITURE VS TEMPERATURE–HUMIDITY INDEX AT VARIOUS POINTS

Temperature-Humidity Index readings derived from temperatures of air which is nearly saturated are not comparable from a comfort standpoint to Temperature-Humidity Index readings derived from dry air. For instance, at 115° F and dew point 55° (relative humidity 15%), the Temperature-Humidity Index is 91. To reach a Temperature-Humidity of 91 at saturation, a temperature and dew point of 95° F would be needed. A 95°/95° F temperature-dew point combination would result in virtual decimation of a population, while 115°–55° F temperature/dew points are common in many populated areas. The humiture draws a distinction between these two circumstances. A 95°/95° F temperature/dew point combination would result in a humiture of 141, while the 115°/55° F situation gives a comparatively tolerable humiture of 120. Unlike the humiture, the Temperature-Humidity Index rises too slowly at higher vapor pressures.

CONCLUSIONS

Because it relates the temperature and moisture content of the air on a biological basis to an equivalent, real dry air temperature, the humiture expresses the relative comfort of the air more satisfactorily than other figures. Further, its cornerstone, the humit, gives directly the effect of moisture on relative comfort, so that one has the satisfaction of knowing separately the effect of temperature and of the moisture content on his comfort. Also, one can tell, by means of the humits, the amount of moisture present with respect to a reference point, and any changes in the moisture content of the air. Finally, the simplicity of the humiture formula makes it easy to understand and to use.

REFERENCES

1. Heavener, Osborn Fort. All About Humiture. *Weatherwise*. 12-2, April 1959, 56–85.
2. Thom, E. C. The Discomfort Index. *Weatherwise*. 12-2, April 1959, 57–60.
3. Landsberg, Helmut. Bioclimatic Work in the Weather Bureau. *Bulletin of the American Meteorological Society*. 41-4, April 1960, 184–187.
4. Hendrick, Robert L. An Outdoor Weather-Comfort Index for the Summer Season in Hartford, Connecticut. *Bulletin of the American Meteorological Society*. 40-12, December 1959, 620–623.

* 5000 Parkside Ave., Phila. 31, Penna.

AMS Notes

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To ensure that members continue to receive American Meteorological Society periodicals promptly and with as little re-mailing as possible, the Society acknowledges receipt of changes of address *only if the change has been received directly from the member concerned.* Changes of address noted from other sources cannot be acknowledged. The Society's acknowledgment by post card confirms the new mailing address:

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AMS Membership Directory

The American Meteorological Society plans to publish a Membership Directory in the spring of 1961. It will be printed alphabetically in the five membership categories (Professional, Member, Student, Associate, and Corporation). There will also be a geographical listing by states and foreign countries.

All members will receive a Directory Index Card with the 1961 Annual Dues statement. Each member must enter his name and address *on both halves* of the card as he wishes them to appear in the Directory. The card must be returned fully completed, either printed or typed, by **15 March 1961,** or it will not be possible to process it and include the member's name in the Directory.

The headquarters staff makes these announcements about changes of address and the Membership Directory in hopes of enlisting active support and cooperation for its goal of increasing service to members while decreasing paperwork.

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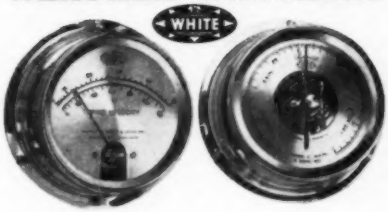

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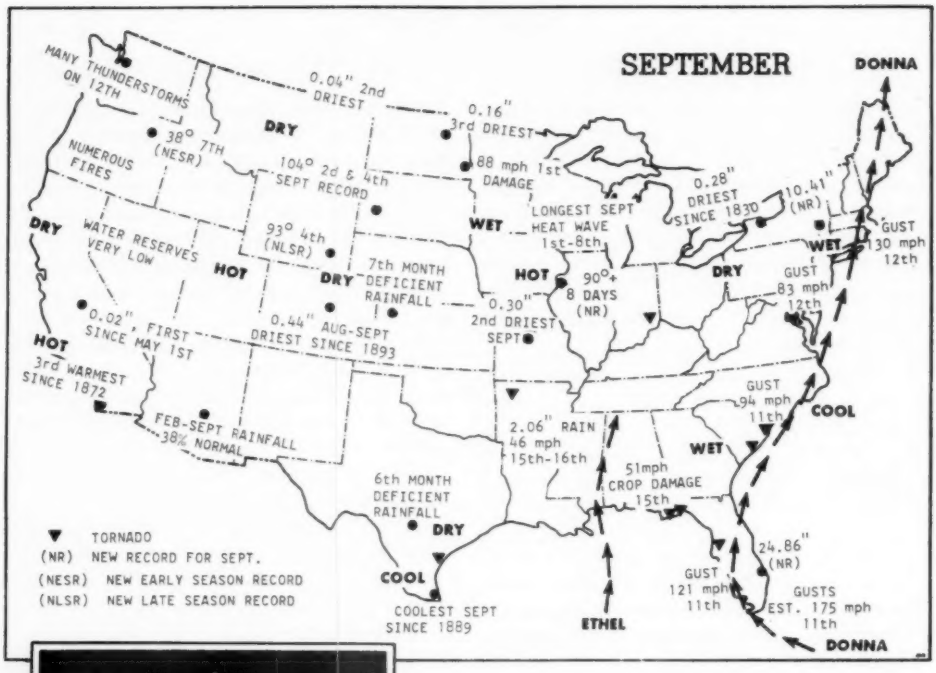


Weatherwatch

Data by Office of Climatology, USWB.

Donna Features Otherwise Routine Autumn

DAVID M. LUDLUM

September was a warm month throughout the country. It was particularly so in a vast latitudinal band across the central part of the nation, from California east to the Ohio Valley where some areas averaged as much as four degrees above normal. Only three small peripheral areas ran as much as one degree below normal; the immediate coastal strip north of San Francisco, the Louisiana delta, and southeastern Texas. Elsewhere summer continued on.

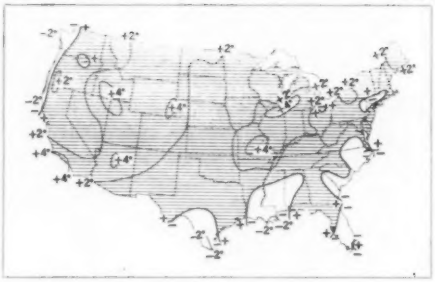
Most of the nation lay under the influence of a strong-for-the-season westerly flow, resulting from a fairly tight pressure gradient between above normal pressure over central and northern United States in combination with a broad band of low pressure from Alaska across Hudson Bay to southern Greenland. On most daily weather maps of the month air flow came in from the Pacific and sped eastward rapidly to the Atlantic States. It brought essentially dry, homogeneous air masses with little frontal activity.

The precipitation chart for September shows that the only areas with excessive rainfall were coastal locations under the influence of one or more tropical disturbances. These kept Florida and the eastern Gulf coast both wet and cool throughout the month, to form a marked exception to the general pattern of sunny skies and very dry conditions elsewhere.

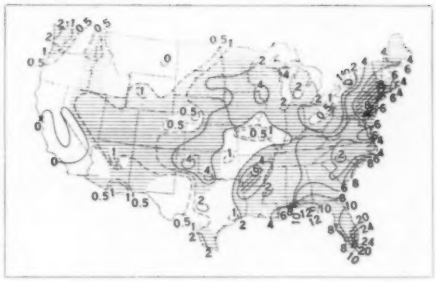
CIRCULATION—The mean circulation map for September, with its lack of continental troughs and fronts and generally west-east streamlines of flow, hides the true nature of the month since it did produce great variations in pressure features from week to week. Opposing departures from normal tended to become obscured by the means.

The month opened with a strong continental anticyclone established over the central and southern Plains where it had been causing a heat wave of major proportions for so late in the season by circulating dry continental air from the Southwest deserts over most of the country west of the Appalachians, producing the warmest weather of the year in the upper Mississippi Valley and in much of the Northeast the only 90° temperatures of the entire summer.

On the 6th the center of the great continental high, almost stationary for eight days over Kansas and Missouri, commenced to move eastward and stood



Departure of Average Temperature from normal in degrees Fahrenheit. USWB chart.



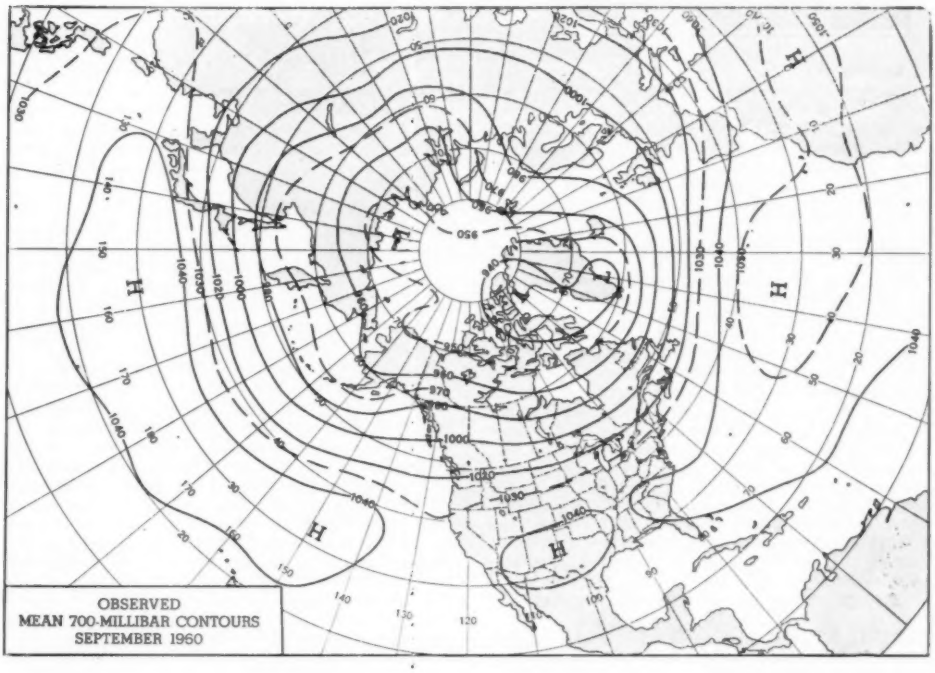
Total Precipitation in inches. USWB chart.

over the Atlantic seaboard on the 8th. At this time two major developments were under way: DONNA, already a *great* hurricane, was making its way west-northwestward just north of the Greater Antilles, and a trough of low pressure had occupied the space over the Great Plains left vacant by the departing continental high. On the 10th and 11th the axis of this trough lay north-south over the Mississippi River Valley, and into the vigorous southwesterly flow on the eastern side of the trough the center of DONNA was steered and here found the impetus for its spectacular dash north-northeastward along the Atlantic seaboard on the 11–12th.

On the 12th the dynamical influence of DONNA had created a tremendous trough in the upper air from the deep Arctic to the Gulf of Mexico—a vast current of polar air rushed southeastward out of Canada to engulf all sections of the country east of the Rocky Mountains, bringing the first true autumnal weather in its wake. DONNA joined with a Hudson Bay low to form a deep cyclonic vortex over central Quebec, and this controlled the weather of the eastern two-thirds of the continent for the next three days.

(*Continued on page 263*)

The upper-air map below shows the pattern of air flow for September at about 10,000 feet, on which the average weather largely depends. The contours lines represent the mean height of the 700 mb. pressure level. Figures are in tens of feet: 1020 = 10,200 ft., 980 = 9,800 ft., etc. Chart by Extended Forecast Section, USWB.



Weatherwatch

Data by Office of Climatology, USWB.

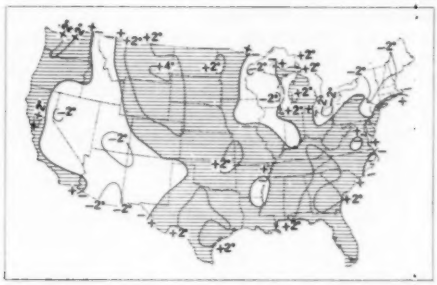
October went into the record books as a month without spectacular storm activity—hence there was an absence of weather headlines such as its predecessor had produced. Most sections of the country, with the notable exception of Texas and the Southwest, enjoyed frequent spells of "October's bright blue weather" for a pleasant, open month. Nevertheless, though temperature means approached normal in practically all sections, there were some remarkable thermal extremes noted. For instance, at Bismarck, North Dakota, the 91° registered on the 4th tied both the all-time October maximum and also set the warmest-so-late-in-the-season mark. Conversely, a direct north flow on the 19th dropped the mercury to +5°, this being the lowest ever registered so-early-in-the-season in the 90-year record there.

In the realm of precipitation most stations were either decidedly dry or decidedly wet, and here the contrast between northern and southern sections was remarkable. Across the northern third of the country, from Washington and Oregon eastward to New England, it was dry, distressingly dry in the northern Plateau and northern Great Plains. But in a large area of central and southern United States an abundance of moisture fell from the clouds with some all-time rainfall records set on the Texas Gulf coast. Only in the extremities of the Southland (Southern California and Georgia and Florida) did the rainfall in this latitude average out as light in October.

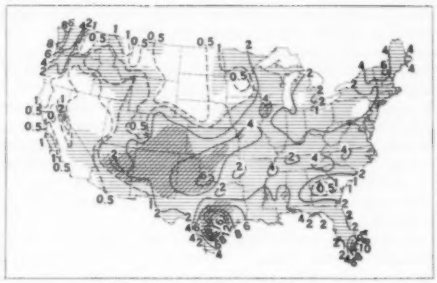
CIRCULATION—An unusual feature of the weather charts in October centered around the presence of several cyclonic circulations with closed isobars which formed at relatively low latitudes and moved eastward wholly within the borders of the United States. Most upper-air charts had at least one of these features imbedded in the atmospheric currents, south of the main westerly circulation to the north.

During the first days of October the westerlies picked up from the low stages of late September as fronts swept quickly from western Canada southeastward in regular succession. But to the south the low pressure influence of latter September persisted. On the 1st and 2nd a small low prevailed over southern California, though it failed to produce any precipitation pattern. Following this another tropical disturbance developed in the Gulf of Mexico on the 6th, as ETHEL had done in the previous month, and moved northward up the Mississippi Valley with a good rain pattern over most of the Southeast.

But the most interesting developments of the month lay in the Southwest where two formations of low pressure, unusual for this season, dominated the weather scene. The first of these took form as a deep polar trough moved in from the Pacific Ocean on the 7th and remained temporarily poised over the Pacific states; by the 9th a closed circulation had developed over Nevada and central California to control all air currents over the western third of the country for the next two days. A copious rainfall spread over the southern Plateau, the first in many weeks, to bring much-needed catches to southern



Departure of Average Temperature from normal in degrees Fahrenheit. USWB chart.



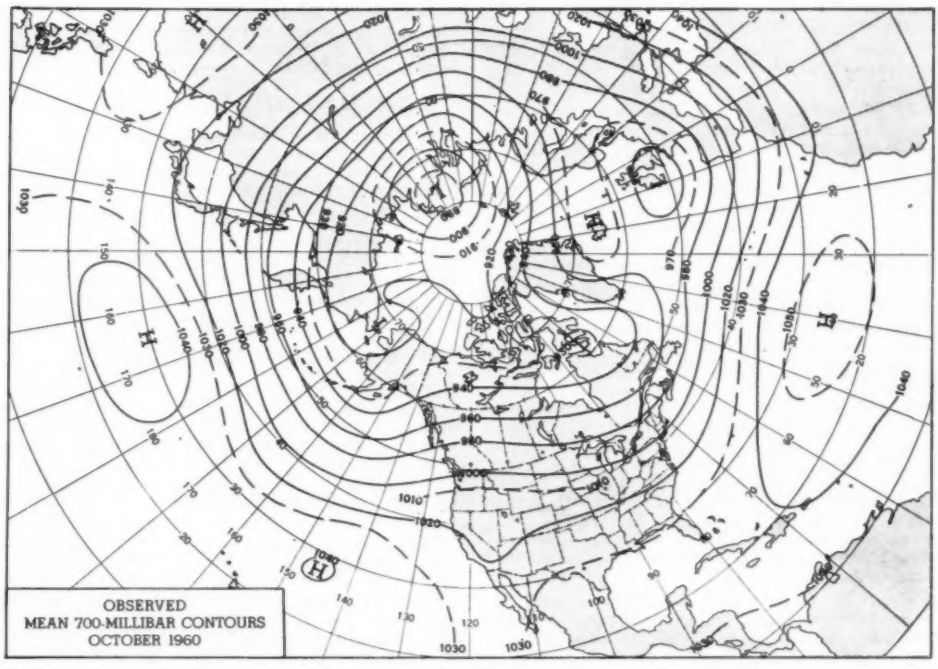
Total Precipitation in inches. USWB chart.

Nevada, southern Utah, Arizona, and New Mexico as the trough progressed slowly eastward.

Again on the 14–15th good rains fell in this area as the first trough, retrograding westward, developed another closed circulation over the Southwest. This spawned a surface low over northern Mexico which migrated eastward to spread a heavy rainfall into Texas on the 16–18th. The upper-air chart of North America on the 16th was composed of two giant, cyclonically-spinning pinwheels—one over Arizona, the other over Hudson Bay—each with its own independent wind system.

A major change in the weather map took place on the 17–18th as the Hudson Bay feature and the Arizona low joined forces to form an extensive trough reaching from Baffin Land in the Arctic to the Gulf of Mexico in the tropics. At the same time the first major anticyclone of the month appeared in the Canadian Northwest. With a central pressure of 1041 mb/30.74″ over northern Saskatchewan and a tight gradient eastward, the way was open for cold air to pour southeastward. It dropped the mercury to zero in North Dakota for the first time in many Octobers and brought the first hard freeze to all of the central valleys. In advance of the cold air mass, an active low formed on the cold front in Oklahoma, soon consolidated with the previous Mexican low, and the combination moved northeastward through the Ohio Valley to New England accompanied by a very extensive rain shield over all sections east of the Missouri River.

After this active front cleared the Atlantic Coast on the 20th, the upper-air flow pattern took on a more seasonal aspect. A western ridge-central



trough-eastern ridge regime took over with pressure impulses entering northern British Columbia from the Gulf of Alaska at about 48-hour intervals. The westerly flow index reached its highest point of the month on the 20–24th. Thereafter low pressure centers from the North Pacific tended to move farther and farther southward. On the 24–25th a circular low at the surface moved across New England to cause an early snowstorm in central Massachusetts and southern New Hampshire, and this was followed by an invasion of frigid air to bring on the first general freeze in the Lower Lakes region and the Northeast.

A second southeastward-moving low wandered from the Upper Lakes on the 26th to the Carolina coast on the 28th and then remained offshore as a vigorous circulation until the 31st. The southeastward trajectory and sluggish movement of these lows during late October reflected the growing influence of a building anticyclone over Labrador and southeastern Canada. A large blocking feature had developed between Greenland and Iceland as October progressed to provide the principal pressure anomaly of the month for the entire hemisphere. Pressure averaged 12 mb/0.37″ above the mean for the entire month there. The extension of this anticyclone westward to Labrador as October drew to a close caused a shift in storm tracks over most of North America. Thus, on the last day of the month a vigorous surface low with circular isobars was centered over Wisconsin with a sharp rain-producing front south to the Gulf of Mexico.

OCTOBER NOTES

Worcester Mass. Snowfall of 3.6″ on 24–25th was the heaviest for October since records started at the airport. Narrow snow band extended from New Hampshire to Rhode Island. Six inches fell in southwest New Hampshire; 14″ atop Mt. Washington.

Roanoke, Va. October was a beautiful month with temperatures and precipitation only slightly above normal. No severe storms were reported.

Key West, Fla. The high temperature of 91° on the 27th and 28th exceeded the all-time max. for those dates by 4 and 3 degrees, and represents the highest ever recorded so late in October.

Austin, Tex. Torrential rains fell on the night of 28–29th with amounts in the Austin area up to 10″. A major flood moved down the Colorado as a result. Monthly total rain of 12.31″ was the second heaviest for October. Eight lives were lost in the flood as cars were trapped on low-water bridges. Property damage $2.5 million.

Corpus Christi, Tex. This was the rainiest October of record since 1887. Rainfall 15.49″ downtown and 12.51″ at airport. Greatest in 24 hours was 7.25″ on 16–17th.

Albuquerque, N. M. This was the wettest October since 1911 and the coldest since 1949. The 24-hour total of 1.31″ was a record for this month at the present WB site. The storm at mid-month was very unusual. Almost continuous rain from early morning of the 15th until late afternoon of the 18th gave a storm total of 2.46″, apparently the greatest single storm total since 1933. Many dirt roads and streets were almost impassable and runoff flooded lowland areas.

Fargo, N. D. Weather conditions during the month were favorable for harvesting of late crops and other outdoor activities. The first hard freeze of the season occurred on the 18th, making this an unusually long fall growing season. Rain on the 29th–30th was very beneficial.

Rapid City, S. D. Dry! One of the two driest Octobers on record. Only a trace was observed. No measurable rain since 22 Sept.

Glasgow, Mont. October was the 9th consecutive month with below normal precipitation. Total rainfall now through the year is 6.67″ which is only 55% of the normal for that period.

Reno, Nev. Another month with very deficient moisture (only 0.18″) and water reserves are dangerously low. Reservoirs in the high Sierras are very low, and most other reservoirs are virtually dry. Ranges are in poor condition and feed is low.

Santa Maria, Cal. The heavy rain on the 5–6th accounted for the heaviest rainfall in October during the 18 yrs of WB record. During a 3-hour period 1.79″ was recorded. Rain resulted from remnant of a Pacific tropical storm.

Burbank, Cal. An uncommonly dry October with less cloudiness than usual. Slightly warmer than normal. On the 15th Santa Ana winds reached gale force in many nearby areas, causing scattered minor damage. Sea level pressure of 29.56″ on 9th was the lowest of record for October.

ALASKAN NOTES

Juneau. October was an unusually cloudy (12% possible sunshine), windy (11.2 mph average), and rainy (8.95″) month. Max. 53°, min. 35°.

Fairbanks. Most of the 0.92″ precipitation fell early in the month when temperatures were warmer so snowfall amounted to only 3.9″. Max. temp. 48° on 22nd, min. 3° on 30th. Barometer ranged from 30.57″ to 28.92″.

Barrow. Temperature averaged 5.5 degrees below normal. Max. 33° on both 2nd & 3rd; min. −8° 31st. Only zero day on the 31st. Trace or more of snow fell every day except the 23rd. Total fall 6.4″. Lowest pressure 28.71″.

HAWAIIAN NOTES

Honolulu Airport, Oahu. A funnel cloud was observed northwest of the station on the 20th from 1448 to 1459. October max. temp. 90°, min. 68°. Rainfall of 1.16″ was 0.73″ below normal. Barometer ranged from 30.09″ to 29.87″.

PUERTO RICAN NOTES

San Juan. Max. temp. 91°, min. 70°, average 80.6° or 0.9° above normal. Rainfall on 10 days totaled 4.63″. Barometer ranged from 30.05″ to 29.84″.

CANADIAN HIGHLIGHTS

British Columbia. Excessive storm activity in the Gulf of Alaska maintained a supply of mild air over western Canada which produced temperatures 2 to 4 degrees above normal in British Columbia. Precipitation exceeded 20″ in a band along the Pacific Coast and only the southeastern interior reported below normal precipitation. The heaviest precipitation in the country, 34″, was reported from Hebert Inlet on the coast. Duncan on Vancouver Island with a mean temperature for the month of 54° was the warmest location in Canada.

Prairie Provinces. October was a mild dry month across the southern Prairies. Mean temperatures were in excess of 40° and Vauxhall, Alta., reported a national maximum temperature of 86°, while on

the other hand minimum temperatures approached zero during the third week of the month in southern Saskatchewan. A freezing temperature on 9 October at Edmonton ended a frost-free period of 155 days which was the longest on record since 1881.

With the exception of the immediate Winnipeg and Edmonton regions, it was another dry month, particularly in southern Saskatchewan. At Regina, following the driest September on record, the October precipitation amounted to 0.01″, the lowest in 58 years of record.

Ontario and Quebec. Normal temperatures, light precipitation, and sunny skies were typical of October 1960 in southern Ontario and Quebec. Rainfall was locally heavy in the Montreal region as was snowfall in Ontario north of Lake Superior where several stations had in excess of 12″ during the month. Following a major cold outbreak on 24 October, a blanket of snow spread over a large area of southwestern Ontario in the lee of the Great Lakes leading to a few hours of early season traffic difficulties.

Atlantic Provinces. Although somewhat more cyclonic activity occurred over the Atlantic Provinces than in the preceding month, such activity was still below normal for the autumn season. Temperatures were slightly below normal and, although precipitation totals were high in some areas, they were, for the most part, below normal and many suburban and rural areas were still suffering from water shortages at the end of the month. At Halifax, October marked the seventh consecutive month with subnormal precipitation and above normal sunshine.

The North. As a result of circulation blocking action near Greenland, temperatures in the northeast Canadian Arctic averaged 4–6 degrees above normal during October. Precipitation was well above normal in the same area with Clyde reporting in excess of 80″ of snowfall. The western Arctic had slightly below normal temperatures and seasonable precipitation. Minimum temperatures of −28° at Eureka and −23° at Alert were the coldest in the nation during the month.

(*Courtesy of Meteorological Branch, Air Services, Department of Transport, Canada*)

September (*Continued from page 259*)

A third period commenced at mid-month as the Quebec disturbance began to fill, its trough to flatten out in the south, and a westerly flow to resume across the country. An interesting feature developed in the South at this time in the form of tropical storm ETHEL in the central Gulf of Mexico. This had the appearance of a cut-off low circulation in the southern end of the main trough, but with the main westerlies breaking through the central part of the trough to sweep across northern and central United States unhindered by developments to the south. ETHEL never did develop her potential, and the westerly air stream to the north moved frontal systems rapidly across the continent during the period 15–20th.

On the 20th a marked polar trough over Canada took form with a narrow tongue connecting to a circulation aloft over California. By the 24th the southern end of the trough had traveled eastward to Texas and presented a very distinctive pressure feature over the Mississippi Valley with a deep, but still very narrow trough. Both to the east and the west high pressure built up quickly to increase the gradient and stimulate a rapid flow. A sharp front in the form of a large curving question-mark followed the trough from Hudson Bay southeastward and then southwestward to a developing depression in the Gulf of Mexico. Once again a cut-off low situation developed with an upper-air circulation stationary over east Texas on the 25–26th. Two minor tropical disturbances formed in the Gulf and moved slowly northward over the middle Gulf coast to bring cloudy skies, cool temperatures, and moderate precipitation to the Southeast. And again the mid-month pattern was repeated in the North as a low center in Hudson Bay stimulated westerly flow and spun cool air streams out of Canada into the central valleys to bring typical autumnal weather to all northern and central sections as the month drew to a close.

MARCH NOTES

HURRICANE DONNA—See *Weatherwise*, October 1960, 210–217.

Block Island, R. I. Greatest amount of precipitation ever recorded in 24 hours fell on 19–20th (8.52″). Monthly total of 11.36″ greatest for any month in 80-year record.

Atlantic City, N. J. With respect to high tide and wave damage, hurricane DONNA appears to have been the third most severe storm in this station's history; exceeded only by the hurricane of 14 September 1944 and the severe extra-tropical storm of 25 November 1950. DONNA passed 80 to 100 miles east about 1100 EST. State Marina had one-minute speed of 58 mph from WNW, 28.38″ barometer at 1220, and 8.2′ tide at 1230.

Wilmington, N. C. DONNA on 11–12th: Fastest one-mile wind 53 mph, NW, at 2359. Peak gust 97 mph WNW, at 2355. Duration of gale force gusts from 1616 to 0240; hurricane gusts from 1940 to 2148 and 2259 to 0100. Lowest pressure 28.41″ at 2150. Rainfall 6.26″. Tides 6 to 8′. The eye was 50–75 miles diameter, passing 10 miles east of station at 2150.

Fort Myers, Fla. DONNA passed over station on 10th with max. sustained wind of 92 mph and peak gust at 121 mph. Hurricane force winds from 0855 to 1100 and 1552 to 2100. Eye passed with lull from 1420 to 1531. Tides 4–7′ above normal. Lowest pressure 28.08″, exceeds former record of 28.14″ in Sept. 1926 hurricane.

Tallahassee, Fla. Two tropical storms, ETHEL AND FLORENCE, produced heavy rains—2.28″ and 4.73″—but no other damage. DONNA missed area completely.

Rochester, N. Y. This was the driest September since 1830—only 0.28″ fell. Also the ninth driest month in 130 years of record.

Rockford, Ill. The average temperature was highest since 1948. The heat wave which began August 30th continued for the first 8 days. Above 90° on 8 of 10 days. Max. of 95° on 7th was highest temp. of season. The arrival of cooler air on 8th was accompanied by thunderstorms and hail.

Columbia, Mo. Second driest September of record (1905–1960). Only 0.30″ fell—total for Aug–Sept only 0.57″.

Lincoln, Neb. September 7th was the close of a period in which the mercury reached 90° or higher on 15 of 18 consecutive days.

Rapid City, S. D. The 104° reading on the 2nd and 4th exceeded the all-time high for September and was also the warmest for so late in the season.

Brownsville, Tex. This was the coolest September since 1889. The average was 2.7 degrees below normal.

Helena, Mont. Warm and dry, but the most noteworthy occurrence, the minimum of 29° on the 8th, was the coldest for that date in the 81-year record. It was the driest September (0.13″) since 1932.

Reno, Nev. Another month with very deficient precipitation has caused further deterioration of ranges and depletion of already very scant water reserves. Precipitation is very badly needed. September produced only a trace.

Red Bluff, Cal. One of the driest two-day periods of record occurred when the relative humidity reached a low point of 3% and did not rise above 14% from 2000/20th until 2000/22nd.

Mt. Shasta, Cal. This has been the driest summer in 27 years. The four-month period June–Sept produced only 0.28″ rainfall.

San Diego, Cal. Average temperature of 72.3° for September is third highest for the month since records commenced in 1872—exceeded only by 72.8° in 1939 and 72.7° in 1958. This was also a sunny month, with 84% of possible sunshine being exceeded only once——in 1956.

ALASKAN NOTES

Anchorage. Precipitation of 4.79″ was greater than any month since August 1953. The first freeze on 26th was two weeks later than normal. The growing season of 140 days for 1960 exceeded the normal by 25 days.

Juneau. Most elements were near normal. Max. temp. 67°, min. 34°.

Barrow. Max. temp. above freezing on only two days. Max. 36° on 26th, min. 10° on 19th—every day but three averaged below normal. Snowfall built up from trace on 1st to 5″ on 18th. Highest barometer 30.24″, minimum 29.19″.

CANADIAN HIGHLIGHTS

British Columbia. British Columbia was the only province experiencing below normal temperatures during the month; the first and third weeks were cool and rainy while warm sunny weather was enjoyed along the south coast during the second week and all of southern British Columbia had fine Indian Summer weather during the final week of September. Wind speeds were again low at Vancouver as September was the fifth successive month with record low values for mean wind speeds. Some freezing temperatures as low as the mid-twenties were experienced in parts of the interior of the Province about mid-September. Ocean Falls on the north coast reported 16.39″ of rain, the highest total in the country during the month.

Prairie Provinces. September was a warm dry and an ideal harvest weather month on the prairies. Temperatures were everywhere above normal as maxima in the high nineties were recorded in southern Saskatchewan and Manitoba. Throughout the prairies the month was noteworthy for the lack of severe frosts as the first frosts were a week or so later than usual. In Alberta and Manitoba there were no general killing frosts during the month, but one occurred in Saskatchewan on 28 September which was, however, too late to cause serious damage.

It was the driest September on record in many locations in southern Saskatchewan. At Regina, where precipitation data are available back to 1884, a precipitation total of 0.11″ in September 1960 equalled the driest September on record of 1893. Several stations reported monthly precipitation totals of less than one-tenth of an inch.

Ontario and Quebec. Southern Ontario also had an exceedingly dry September. At Toronto City the precipitation was 0.31″ which was the lowest September precipitation since observations began in 1840. The low pressure systems moving across the Province were rather weak and diffuse and were usually well to the north in most instances leaving the south relatively dry. While temperatures were near normal in northern Ontario, they were well above in southern Ontario as a result of the steady eastern migration of high pressure areas through the Province.

Southern Quebec experienced decidedly warm weather during the first ten days of the month, but over the month as a whole temperatures were near normal. Precipitation was near normal in southern Quebec, while in northern Quebec September provided no relief from the wet conditions which persisted throughout all the summer months of 1960. The month was mainly damp with only occasional fine days. At Knob Lake there was eleven inches of snowfall on the 13th.

Atlantic Provinces. The weather pattern in the Atlantic Provinces was similar to that of the past several months. There continued to be a minimum of cyclonic activity and it was not until "Hurricane Donna" approached the region on September 12 that appreciable rainfall occurred. As the storm center moved from the State of Maine across a narrow portion of Quebec and out over Labrador, sizable rains occurred over some sections of New Brunswick and eastern Quebec. At the same time, the winds associated with the tropical storm reached gust speeds of 80 mph in both western Nova Scotia and in New Brunswick. This produced some tree damage causing telephone line and power line damage and some of the fruit crop was torn from the trees. The slight change in weather pattern after the hurricane produced sufficient rain to check the forest fires in Nova Scotia.

In Newfoundland, the period from July through September surpassed all previous records for favourable summer weather at Gander Airport. During the three-month period there was less than five inches of rain and over 600 hours of bright sunshine. The period of record at Gander extends back over 24 years and never has there been less rain during this three-month period.

The North. While the mainland Canadian Arctic experienced slightly below normal temperatures during the month, the northern Arctic Islands were again warmer than normal. Maximum temperatures in excess of 32° were experienced at all stations except Alert and Mould Bay, and only Alert and Eureka had minimum temperatures of below zero. A minimum of − 12° at Alert was the coldest temperature in the country during the month. Precipitation was generally less than an inch in the western Arctic and greater than one inch in the eastern Arctic. Clyde River reported 21″ of snowfall during the month, while at the end of the month there was 15″ of snow on the ground at Alert.

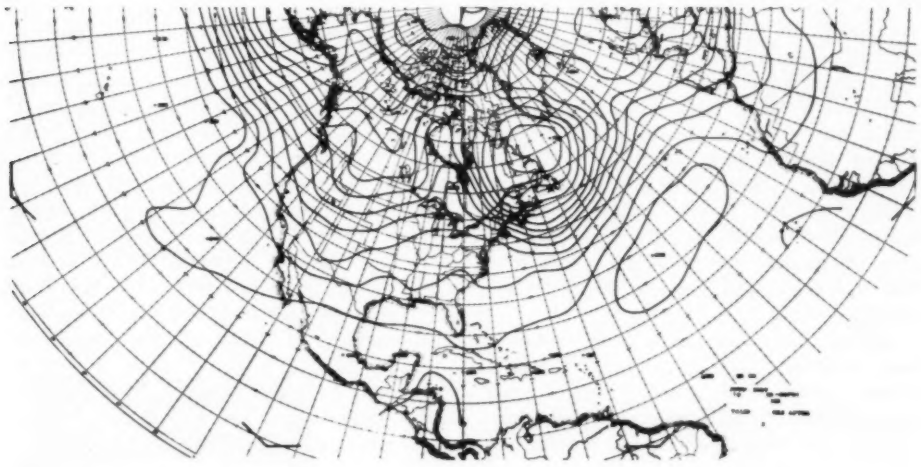
(Courtesy Meteorological Branch, Air Services, Department of Transport, Canada)

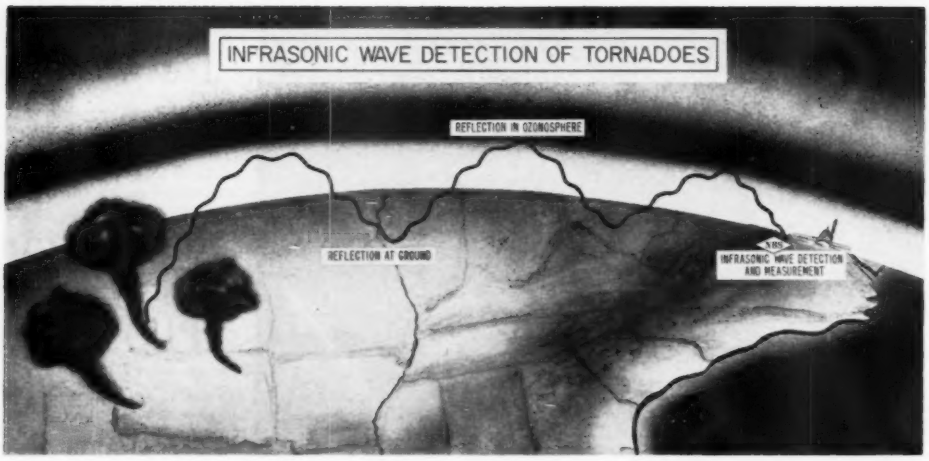
THE WEATHER PLOTTER

An electronic-plotter which automatically draws a complete forecast map of the Northern Hemisphere has recently been put into operation by the U. S. Weather Bureau at the National Meteorological Center at Suitland, Maryland. The device represents another step toward full automation of weather data. It was developed by Electronic Associates at Long Branch, N. J.

Basic data from more than 500 weather stations around the world are employed to produce forecast charts for 12 to 72 hours in advance. The prognostics are programed on a computer and recorded on magnetic tape. The Weather Plotter presents the data directly from the tape to a digital-to-analog converter. The converter, in turn, instructs the mechanical hand of the Plotter to trace automatically the contours or isobars on a 30″× 30″ chart.

The Plotter requires approximately three minutes to produce a full chart. Sixty-four weather maps can be produced and transmitted by facsimile per day. Part of a 500mb chart is reproduced below.




INFRASONIC WAVE DETECTION OF TORNADOES
REFLECTION IN OZONOSPHERE
REFLECTION AT GROUND
INFRASONIC WAVE DETECTION AND MEASUREMENT

INFRASONIC waves generated in the earth's atmosphere by earthquakes, pressure disturbances from tornadic storms, and geomagnetic disturbances have been recorded at the National Bureau of Standards. For what is believed to be the first time, studies were made of the quantitative relation between the source of the disturbance and the incident sound pressure, the direction of approach of the incident wave, and the speed of the wave across the earth's surface (usually called the trace velocity or the horizontal phase velocity). These studies were begun under the direction of the late Peter Chrzanowski, and are being continued by the Sound Section staff.

A system of detectors of the type employed by the Bureau near its Washington laboratories could be used to follow the paths of tornadic disturbances and to supplement knowledge of upper atmospheric physics, especially with respect to the sun's effect on the earth's magnetic field. Also of interest are very-low-speed pressure waves which may be gravitational waves resulting from shifts among atmospheric layers of varying temperatures or wind speeds. The Bureau is planning for a sound-recording installation similar to that in Washington to be located near Boulder, Colorado.

Although the atmosphere may sometimes seem relatively free from audible sounds, natural sounds of substantial intensity are always present. These sounds are propagated through the atmosphere at infrasonic frequencies—frequencies lower than the human auditory threshold of about 15 cycles per second. In a homogeneous atmosphere free of winds and temperature variations, the speed of sound varies as the product of the square root of the absolute temperature and a constant related to the medium through which the sound travels, and is equal to the frequency times the wavelength. The rate at which sound power is absorbed and dissipated into heat is a strong function of frequency; the fraction of sound power absorbed per unit distance of propagation is roughly proportional to the square of the frequency. The net effect of this relation is that only sounds having very low inaudible frequencies can be propagated to great distances.

A natural sound observed in Washington when the background noise is low appears to originate in the vicinity of severe tornadic storms up to 1200 miles away in the central United States. Weather Bureau reports of 5 May 1960 show 19 tornadoes and funnel clouds in Oklahoma and Texas and one tornado in northwestern Kansas that could have produced the sound waves received at Washington during a 4¼ hour interval on that date. Similar waves believed to be from tornadic storms were received during eight such time intervals in May 1960. Properties characteristic of such tornadic signals on arrival are periods between 12 and 50 seconds, speeds about equal to that of sound in air, and sound pressures normally less than 1 dyne per square centimeter at these distances.

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FIG. 6. Cosmic radiation equipment units to the right are contained in the ash can which is mounted in the aircraft instrument bay.

(*Continued from page 236*)

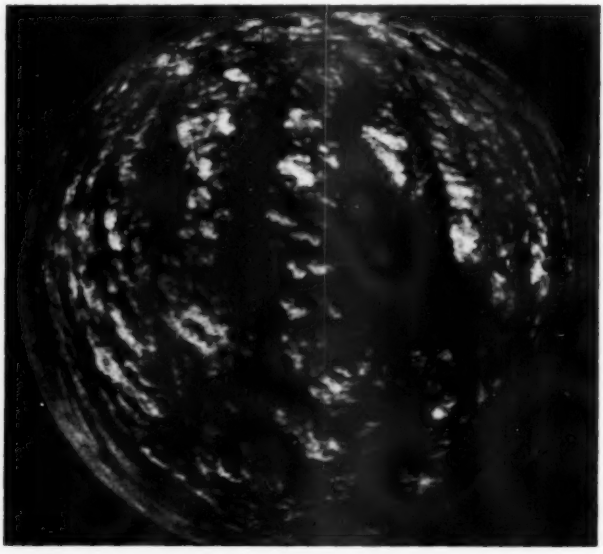
Figure 6 shows the cosmic radiation measuring equipment used as a separate package.

For correction and conversion of indicated values to basic data, it is necessary to perform calibrations of all instruments. These calibrations can be divided into two types: ground or instrument calibrations and flight calibrations. The ground calibrations can be considered conversions from a measurement of some effect to a corresponding value of the desired parameters; e.g., the measurement of temperature is based upon the electrical resistance of a thermistor which varies with temperature. Ground calibrations relate a specific resistance to a specific temperature.

Flight calibrations are the type made to determine the effect of the motion of the aircraft on the measurements; e.g., in the measurement of ambient (free air) temperature, the temperature at the sensing point is increased by the speed of the aircraft. Calibration is necessary to determine the factor used in correcting the indicated temperature to obtain ambient temperature. Flight calibrations are performed to correct measurements of: temperature, true air speed (and, effectively, wind speed and direction), pressure altitude, and indicated air speed.

At the present time, many flights have been performed successfully using selected portions of the equipment. It is anticipated that operation of the complete system will become routine in the near future. Data obtained by this aircraft will be corrected and tabulated in booklet form and made available for exhaustive studies by all interested meteorologists. The booklet will contain all information pertinent to the particular flight, including a flight path, weather maps, tabulated data, and graphs of the various parameters.

In summary, it can be stated that measurements of any atmospheric phenomenon of the troposphere or lower stratosphere and larger than a few miles can be obtained by use of the system described above. Comparatively speaking, one is able to bring a microscope to bear in studying meteorological problems of practical importance and of broad scientific interest.

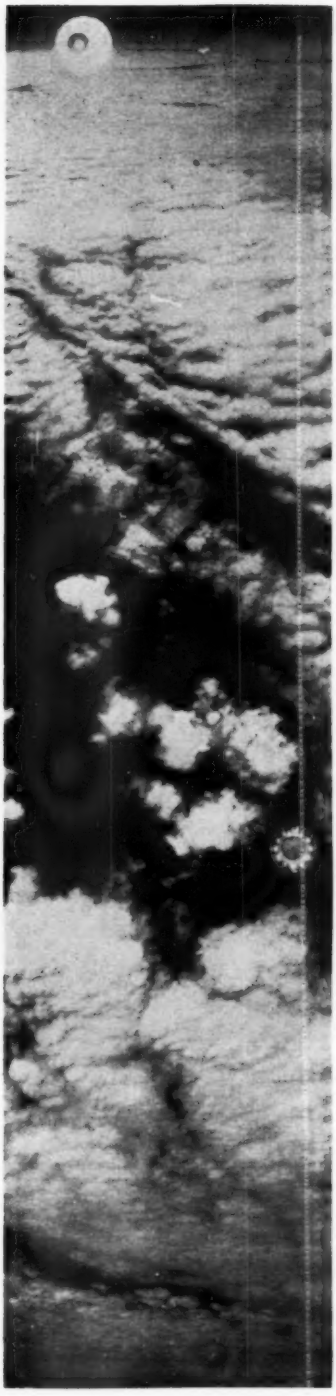


Left.

FIG. 7. Black and white sample of a 16mm color photograph taken with wide-angle time-lapse camera.

Right, on opposite page.

FIG. 8. Sample of consecutive photographs taken with the 70mm camera.



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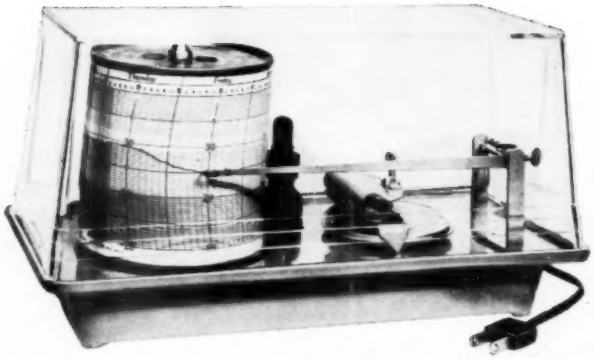

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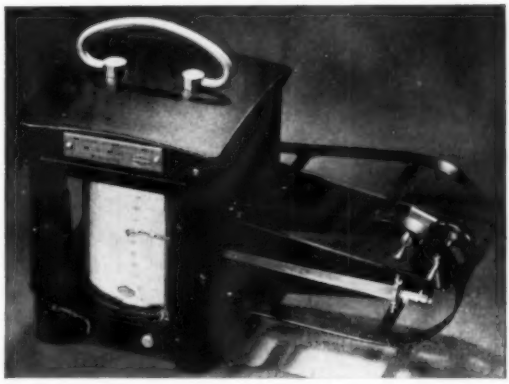

Thermograph Hygrothermograph

No. 156. Thermograph. A robust, compact, and easily portable recording thermometer that gives accurate measurement at low cost. Temperature sensitive element is a high quality bimetallic coil whose curvature changes with temperature variations actuates a pen arm. Charts measure $3\frac{1}{2}$ inches vertically for temperature and $11\frac{1}{2}$ inches horizontally for time. Recording mechanism is housed in an attractive metal case with three glass panels. Temperature element is exposed at side for free air circulation. Standard range is 0° to 100° F. A special feature enables one to adjust or correct reading by simply turning a set screw. This permits instrument to be adjusted according to season to extend range. Seven-day or 24-hour recording period; specify one. Supplied with pen, ink, and 55 charts. Size: 10 x 6 x $6\frac{1}{2}$. Weight: 6 lbs. 10 oz. **$85.00**

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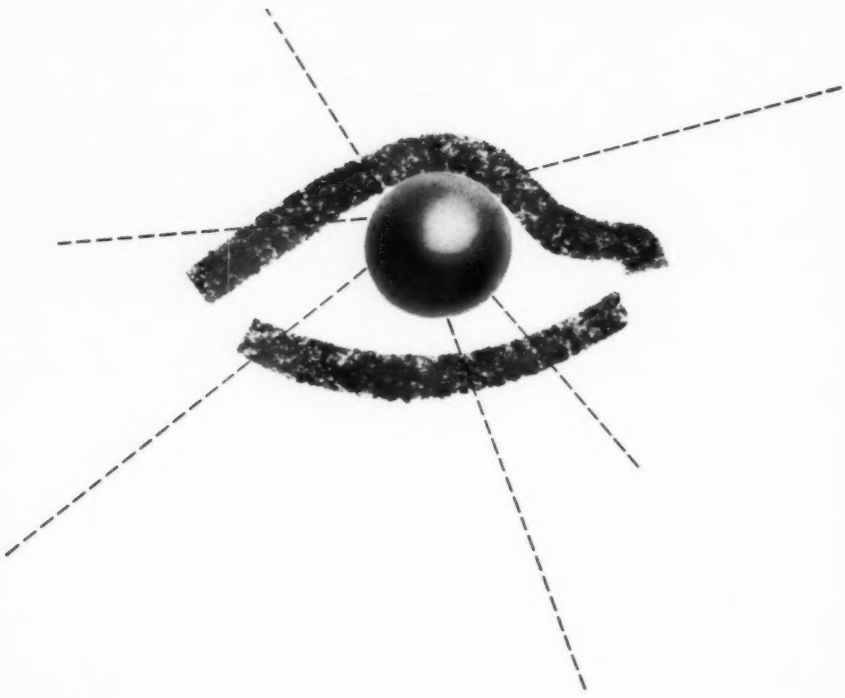

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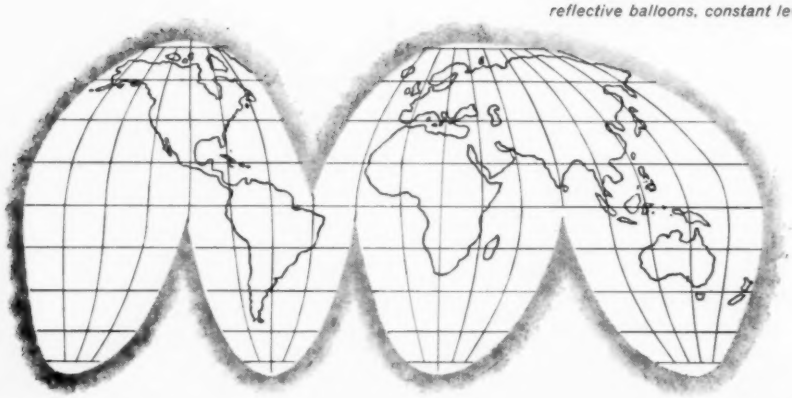
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